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JOSEPH HYDE PRATT, State Geologist

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Zircon, Monazite and Other Minerals Used in the Production of Chemical Compounds Employed in the Manufacture of Lighting Apparatus

BY

JOSEPH HYDE PRATT, Ph.D.

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LETTER OF TRANSMITTAL

Chapel Hill, N. C., October 1, 1915.

To His Excellency, Honorable Locke Craig,
Governor of North Carolina.

Sir:—I have the honor to submit herewith for publication as Bulletin 25 a report on Zircon, Monazite and other Minerals Used in the Production of Chemical Compounds Employed in the Manufacture of Lighting Apparatus. There is a renewed interest in the deposits of these minerals in North Carolina, and the present report takes up not only a description of the localities in which these minerals are found, but is a technical review of the development of the lighting industry.

Very truly yours, Joseph Hyde Pratt,
State Geologist.

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Zircon, Monazite and Other Minerals Used in the Production of Chemical Compounds Employed in the Manufacture of Lighting Apparatus*

By

JOSEPH HYDE PRATT, Ph.D.

INTRODUCTION

Experimental work has been carried on and is being continued in regard to the value of the different metals and compounds in the manufacture of various forms of apparatus for lighting purposes. These investigations and inventions have led to the practical introduction of certain metals and metallic oxides into the arts which before this time had little or no commercial value. With the demand for these metals and metallic oxides there at once arose the question of their sources of supply, which has resulted in the mining of a number of minerals that were formerly supposed to be extremely rare in their occurrence, but which have been found in considerable quantity.

The metals and the metallic oxides that are now being used or experimented with for incandescent and electric lighting purposes are zirconia, yttria, thoria, tungsten, tantalum, titanium, uranium, platinum, osmium, cadmium, cerium, lanthanum, and didymium oxides. With the exception of cadmium, uranium, osmium and titanium, all these materials are being used commercially in the manufacture of different lamps and are obtained from the following minerals: Monazite, zircon, gadolinite, columbite, tantalite, and wolframite. The use of cadmium, uranium, and titanium for lighting purposes is still in the experimental stage, and although cadmium, uranium, and titanium lamps have been made, they are still principally of scientific interest.

It has happened several times that the metal or metallic oxide used in the manufacture of some particular lamp has been replaced by another; as, the substitution of thoria for zirconia in the mantles of the incandescent lamps.

ZIRCON

The first commercial use of the mineral zircon was in the preparation of zirconium nitrate for use in the manufacture of a mantle for incandescent lamps. These mantles are usually known as Welsbach mantles on account of the discovery made by Auer Von Welsbach, that rare earth oxides, when heated, would become incandescent, and that by utilizing a cotton fabric soaked in the solution of these oxides the cotton fabric could be burned out leaving the oxides, which would retain the

*Prepared in coöperation with the Carnegie Institution of Washington, Dept. of Economics and Sociology.

shape of the mantle, and could be heated with gas. His first commercial mantle was patented in 1885, and the principal oxide used in its construction was zirconia, with small amounts of lanthania and yttria. There were not a great many mantles made in which zirconia as the illuminating oxide was used, for it was found that the mantles made by these oxides were very fragile, and the light emitted was not satisfactory. It was not long before it was discovered that other rare earth oxides gave much better results. The first of these was thoria, which is discussed later under monazite. A few mantles were made with the addition of thoria to the zirconia mixtures, and, while the resultant mantle was better than the first ones manufactured, they were not entirely satisfactory, and it was not long before the thoria mantles were perfected, and entirely replaced by the zirconia. The patent for the thoria mantle was issued in 1886.

Another experiment was made of treating the mantle made of thorium and cerium oxides with silico-zirconates of soda. See page 34 under *Thoria*.

The next demand for zircon was for use in the manufacture of the Nernst electric lamp. The principle of this lamp was discovered about 1896 by Dr. H. W. Nernst, and the lamp was patented in 1897. The first use of zircon in its manufacture was in 1902. The fundamental principle of the Nernst lamp is that certain of the rare earths or refractory oxides will conduct an electric current after they have been heated to redness.

This discovery, which was made by Doctor Nernst in 1896, has resulted in the development and perfecting of the glower, which is now embodied in the Nernst lamp. This glower is composed of a mixture of the rare earth oxides and is made in the form of a small rod or pencil of chalk-like material, having wire terminals at either end. When cold, the glower is an insulator, but by means of the wire the glower becomes heated to redness when a current is passed through these wires, and its resistance gradually decreases until it has reached a red heat, when with 220 volts across the terminals it starts to conduct the current and give light. As stated by Mr. E. R. Roberts:[1]

> The heat generated by this current is not only sufficient to maintain independently the glower in an operating state, but causes the resistance to decrease rapidly still further, resulting in a greater and greater flow of current, which would finally result in a ruptured glower if no external resistance with an opposite characteristic were used. For this reason it is essential that the "ballast," consisting of a fine iron wire inclosed in a glass tube be connected in series with the glower; its function being to act as an automatic regulator to prevent the current in the glower circuit from rising materially above its

[1]Proc. Eng. Sec. Western Pa., Vol. XX, 1905, p. 539.

normal value. In practice the ballast performs its duty so well that the lamp will easily withstand an overload of 25 per cent, and may be operated continuously at 5 per cent overload for extended periods without appreciable injury.

In bringing a glower up to its starting point corresponding to a temperature of 1,200 degrees F., use is made of a small electrical heater composed of two or more small tubes of porcelain about 1½ inches long and one-fourth inch in diameter, which are overwound with fine platinum wire, this being in turn held in place and protected from the intense heat later generated by the glower by an outer coating of porcelain paste. After the glower becomes heated, there is, of course, no further use for the heater, and it is cut out by a small electro-magnet cut-out, which consists of a magnetic coil connected in series with the glower, an armature, and the necessary contacts in the heater circuit. Thus, when the glower has become heated sufficiently, the current begins to pass through it, and when this becomes sufficiently strong the armature is attracted and the contacts are separated, thus disconnecting the heater from the line.

The cut-out and ballast can be considered as permanent fixtures, or parts of the lamp, as there is but little wear and tear upon them, and they are, therefore, mounted directly within the body of the lamp. The glower and heater, on the other hand, have a limited life and have to be replaced from time to time. The surface of the glower before being used presents a smooth, white porcelain or chalky appearance, but after having been in service for about 500 hours it is rough and crystalline in appearance. A standard glower is made which takes 0.4 amperes at 210 volts, and the intensity of the lamps is increased by increasing the number of glowers and providing the requisite ballast and cut-outs. Lamps have been made having 1, 2, 3, 4 or 6 glowers and having maximum intensities varying from 25 to 500 candle power.

The use of Nernst lamps did not become as general as was expected, although for some purposes it perhaps gives better satisfaction than any other style of electric or illuminating gas lamps. Some of the advantages claimed for the Nernst lamp are: (1) The sunlight character of the light produced, which, on account of its close imitation of sunlight, adapts it especially for use in places such as dry goods stores, art galleries, and other places where colors have to be determined and observed; (2) the high voltage of the Nernst lamp, which effects a saving of line losses and wiring; (3) the perfect steadiness of light and the absence of shadow; (4) the extreme flexibility of the Nernst system to lighting, owing to the different units available, making it possible to use both large and small units in the same installation and to obtain

an illumination which is uniform throughout, both in quantity and quality.

A small amount of zirconia has been used in place of lime and magnesia in the manufacture of gas tips for the oxyhydrogen blowpipe. Zirconium carbide was formerly used in incandescent electric lamps, but has been superseded by metallic filaments. This carbide is extremely hard, and valuable as an abrasive; but there is not now much demand for it. On account of its refractoriness, zirconia has been used in the manufacture of refractory crucibles, and linings for electric furnaces. It is also employed in the manufacture of chemical ware; for certain medicinal uses; in the manufacture of opaque glass; and as a polishing powder. Other uses suggested for zirconia are in the manufacture of paints and lacquers where a material is desired that is unaffected by gases, acids, or alkalies; and a small amount of ferrozirconium has been manufactured for use in special steel.

The clear transparent varieties of zircon are valued as gems, but very few of these are obtained in the United States. Very small transparent crystals of zircon are associated with the monazite sands of North Carolina, South Carolina and Idaho, but only occasionally is one found of sufficient size to be valuable. The gem zircon is known as "hyacinth."

Sources of Zirconia

The only minerals that have thus far been produced as a source of zirconia are zircon and baddeleyite (or brazilite).

Zircon is a silicate of zirconium ($ZrSiO_4$), and is commonly found in square tetragonal prisms terminated by the pyramid. It is usually of a grayish, light brown to reddish brown color; occasionally it is found colorless to red and perfectly transparent, when it becomes of value as gem material. In hardness it is 7.5, and it has a specific gravity of 4.65.

The analyses of zircon very often show from a trace up to several per cent of iron oxide. The theoretical percentage of zirconia in zircon is 67.2 per cent; while the zircon, as found in nature, varies from 61 to 66.82 per cent.

Zircon can usually be readily identified by its crystallization, and the test for zirconia.

Baddeleyite,[1] an oxide of zirconium, was discovered first in Ceylon about 1892 and in the same year in Brazil, where it was found in considerable quantity. The Ceylon mineral was described first, and given the name of *Baddeleyite.* The Brazil mineral a little later was given the name of *Brazilite,* but afterwards was found to be the same

[1]Baddeleyite, Nature, Vol. XLVI, p. 620, 1892; Min. Mag., Vol. X, p. 148, 1893. Brazilite, J. B. Min., Vol. II, p. 141, 1892; Min. Petr. Mitth, Vol. XIV, p. 395, 1895. Chem. Zeitung, Jahr, 35, Nov. 1911, pp. 1261-1262.

mineral as that from Ceylon. Its composition is represented by the formula ZrO_2, analyses showing a small amount of iron oxide associated with the zirconia. The locality near Sao Paulo, Brazil, is of commercial importance and some quantity of the mineral has been shipped to Germany as a source of zirconia. Prices quoted for this mineral are as high as $215 per ton. This is considerably less than what has been received for the zircon. The mineral crystallizes in the monoclinic system, and usually in twins. It has a rather perfect cleavage parallel to the basal plane. Its hardness is 6.5, and its specific gravity varies from 5.5 to 6.025. In color it varies from colorless to yellow, brown, and black. The lighter-colored specimens have a greasy to vitreous lustre, while the opaque crystals are submetallic, resembling somewhat the mineral columbite.

There are several other minerals that contain a considerable percentage of zirconia, but up to the present time they have not become of commercial importance. As it is of interest to know these minerals, a list and short description of each are given below:

Other Zirconia-Bearing Minerals

Rosenbuşchite. This mineral contains from 18 to 20 per cent of zirconia, and its chemical composition is represented by the formula $(NaF)_2Ca_3\ (\ (Si, Zr, Ti)O_3)_4$. The mineral crystallizes in the monoclinic system in spheroidal radiating crystalline groups, rarely showing distinct crystals. It has a hardness of 5 to 6, a specific gravity of 3.30, and a vitreous lustre. In color it is light orange gray. It fuses very easily. It occurs sparingly in Southern Norway, associated with zircon, elaeolite, etc., in syenite.

Lovenite. This mineral crystallizes in the monoclinic system, usually in prismatic crystals. It is brittle, has a hardness of 6, and a specific gravity of 3.51 to 3.55. It varies in color from light yellow to nearly colorless, and sometimes is dark yellow to dark brown. It varies somewhat in composition, and contains from 28 to 31 per cent of zirconia. It is essentially a silicate of zirconia and manganese, calcium and sodium. Occasionally there is some titanium oxide present. It has been found in Southern Norway, in Brazil, and West Africa, associated with elaeolite-syenite.

Wöhlerite. This mineral occurs in zircon syenite on several islands in Southern Norway. Chemically it is a combination of a calcium-sodium niobate and a calcium-sodium-zirconium silicate. The zirconia content varies from 15 to 22 per cent. It crystallizes in the monoclinic system, is brittle, with a hardness of 5.5 to 6, and a specific gravity of 3.41 to 3.44. It has a vitreous lustre, inclining to resinous, and varies in color from light yellow, wine yellow to brownish and grayish.

Endialyte (*Encolite*). The composition of this mineral is uncertain, but is essentially a metasilicate of sodium, calcium, zirconium, and with smaller amounts of cerium, iron, and manganese. There is usually a little chlorine present. The mineral crystallizes in the rhombohedral division of the hexagonal system with the crystals often tabular. It has a perfect basic cleavage with a subconchoidal to splintery fracture. It is brittle, with a hardness of 5 to 5.5. It varies in specific gravity from 2.91 to 3.1. It has a vitreous lustre and the color varies from rose red to bluish red to chestnut brown. It occurs in syenite in Southern Norway, West Greenland, and in the United States at Magnet Cove, Arkansas.

Catapleiite. This is a zirconium silicate, represented by the formula H_4 (N_2 Ca) Zr Si_3O, the zirconia content varying in the analyses from 29 to 40 per cent. It usually occurs in thin tabular hexagonal prisms which are brittle, breaking with a conchoidal fracture. It is 6 in hardness and has a specific gravity of 2.8. It varies in color from yellowish brown to grayish blue and violet. This mineral also occurs in syenite in Southern Norway, associated with other zirconium minerals.

Cyrtolite. This is one of the minerals that is credited to the alteration of zircon. Several of these minerals are given in Dana Mineralogy; such as malacon, tachyaphaltite, oerstedite, auerbachite, calyptolite, and are considered as hydrated zircons. The percentage of water in these minerals varies from approximately 1 per cent to over 12 per cent. These minerals, when associated with zircon, would be used commercially with the zircon as a source of zirconia. They are not of any commercial importance except in this way. At the Henderson County, North Carolina, mine, cyrtolite has been found associated with the zircon, and considerable has been shipped with the zircon. No attempt was made to separate the two minerals.

Elpidite. It is a hydrous sodium-zirconium silicate, which has been found at one locality in Southern Greenland. It contains 20.48 per cent zirconia. It occurs usually massive with a fine fibrous or columnar structure, with a silky lustre. It varies in color from white to brick red.

Hainite. This mineral is a silicate of sodium, calcium, tantalum, and zirconium. It occurs in walnut yellow to colorless slender needles or plates imbedded in phonolite in Northern Bohemia.

Hjortdahlite is a silicate of calcium and zirconium in combination, with probably a zirconate of sodium and fluorine containing approximately 20.48 per cent of zirconia. It is found in Southern Norway in syenite.

Lorenzenite. A titanosilicate, represented by the formula $Na_2 (TiO)_2 Si_2O_7$, with part of the titanium replaced by zirconium. The zirconia content is sometimes as high as 11.92 per cent. The mineral is found associated with pegmatite.

Polymignite. This is a dark-colored, nearly black mineral with a submetallic to brilliant lustre, crystallizing in the orthorhombic system. Its crystals are slender prisms with vertical striations, and occur associated with zircon in syenite in Norway. The crystals have a perfect conchoidal fracture, a hardness of 6.5, with a specific gravity of 4.77. This is a niobate titanate and zirconate of the cerium metals with iron and calcium, and contains approximately 29.7 per cent zirconia.

Zirkelite. This mineral occurs associated with baddeleyite at the Sao Paulo, Brazil, locality. It occurs in small octahedral crystals, which have a conchoidal fracture. It is brittle, with a hardness of 5.5 and specific gravity of 4.7 to 4.74. They are black in color, with a resinous lustre. The composition of the mineral is represented by the formula R O. $2(Zr, Ti, Th)O_2$, where *R* is equal to cerium, iron, calcium, and magnesium.

As will be noticed above, the majority of these minerals occur in syenite, and are from one locality in Southern Norway. At the present time they do not represent anything of commercial value.

There are a great many other minerals that contain from a trace to a few per cent of zirconia; such as,[1] melanocerite, caryocerite, and tritonite, silicates of the cerium and yttrium metals, which occur in nepheline syenites in Norway.[2] Homilite, variety erdmannite (michaelsonite, 5.44 per cent ZrO_2) contains 3.47 per cent ZrO_2; and sipylite, a niobate of the rare earths, contains 2.09 per cent of ZrO_2. Zirconia is found in the titanosilicates in the following amounts: Astrophyllite, 1.0 to 5.0 per cent; johnstrupite, 2.84 per cent; mosandrite, 7.43 per cent; annerodite, 1.97 per cent. A uraninite from Colorado gave 7.59 per cent ZrO_2,[3] and sometimes a trace is found in xenotime.[4]

Occurrence and Localities of Zircon

Zircon was for many years considered one of the rarer minerals and not to have very wide variation in occurrence; but it has, however, been proved to be very wide in its occurrence and to be rather widely distributed throughout the earth's crust. In some localities it has been found in such association with certain rocks as to warrant the rock to be given a varietal name; in fact, by some authors zircon is now classi-

[1]Watson & Hess, Bull. Phil. Soc., Vol. I, No. 11, p. 279, 1912.
[2]Iddings, J. P., *Igneous Rocks*, 1910, Vol. I, p. 60.
[3]Hillebrand, W. F., On the Occurrence of Nitrogen in Uraninite and on the Composition of Uraninite in General, Bull. 78, U. S. Geol. Survey, 1891, p. 65.
[4]Iddings, J. P., Op. cit., p. 60.

fied as one of the rock-forming minerals. This more general occurrence of zircon was not discovered until the rocks were more thoroughly studied by means of the microscope, as the presence of zircon could not be determined by macroscopic examination. In many of the rocks the grains of zircon are only of microscopic size.

It is commonly found in the crystalline rocks, especially syenites and granites, occurs in some diorites and pegmatites; and occasionally in gabbros and diabase. Watson and Hess state that it occurs in the following volcanic igneous rocks:[1] quartz porphyry, trachyte, phonolite, tephrite, dolerite, diabase, and basalt among volcanic igneous rocks. It has also been reported to be present in phonolite and basalt tuffs.[2]

Zircon also occurs in a great many of the metamorphic crystalline rocks as gneisses, hornblendic, chloritic and micaceous schists, quartzite, marble. It has also been reported in slates and phyllites.

In sedimentary rocks zircon is also a common constituent. It has been found in sandstone, conglomerates and limestones. In some, in sufficient quantity to make it worthy of consideration as a commercial source; such as zircon in sandstone near Ashland, Va. Zircon is rather commonly associated with many of the magnetic iron ore deposits of the United States, and it has been noted with such ores in New York, New Jersey, Pennsylvania, North Carolina, and Tennessee.

Some of the larger crystals of zircon are found in masses of pegmatite, and it is occurrences of this type that have produced the greater quantity of zircon that has been used commercially. Zircon also occurs in pegmatite, and pegmatized portions of gneisses in very small, clear and transparent crystals. These are found in the pegmatites near Auburn and Paris, Maine; Port Henry and Crown Point, New York; Amelia County, Virginia; in the pegmatites of various counties of North Carolina, particularly Henderson County; and the Wichita Mountains of Oklahoma. It is quite abundant in the pegmatites and pegmatized gneisses of the monazite region of North and South Carolina.

Occurrences of this mineral in commercial quantity are not common, and there are but two localities in the United States where it is thus far known to occur in commercial quantity, one in the vicinity of Tuxedo (Zirconia), Henderson County, North Carolina, and the other near Ashland, Va.

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[1]Watson & Hess, Bull. Phil. Soc., Vol. I, No. 11, p. 285, 1912.

[2]For the natural occurrences of zircon see Thurach, H., Ueber das Vorkommen Mikroskopischer Zirkone und Titan-Mineralien in den Gesteinen, Verhandl, Phys.-Med. Gesell., Wurzburg, 1884, Vol. XVIII, No. 10, 82 pp.; Brogger, W. C. Zeitschr, Kryst, f. Min. 1890, Vol. XVI,; Michel-Levy, Bull. Soc. Geol. de France, 1883, III series, p. 284; Rosenbusch, H., Sulla presenza dello Zircone nelle Roccie, *Atti* della R. Accademia della Scienze di Torino, Vol. XVI.

Zircon from Henderson County, North Carolina

The zircons from Henderson County, N. C., occur in a pegmatitic dike, which is about 100 feet wide and has a strike of N. 50° E. It cuts up through the Pre-Cambrian gneisses, and can be traced for a distance of about one and one-half miles. The upper portions of the pegmatitic dike are badly decomposed and kaolinized to a depth of 40 feet or more. The zircons occurring in this decomposed dike are well crystallized, and are usually prismatic crystals, grayish in color, and terminated by the unit pyramid. They occur for the most part in the feldspar, and where this is kaolinized it permits of an easy separation of the zircon crystals by hydraulic processes. As the feldspar becomes more solid and unaltered, the separation of the zircon is more difficult. When the feldspar is crushed, however, the zircons readily free themselves from the gangue. There are two deposits of these zircon crystals that have been worked—one near the southwestern end of the dike, known as the Freeman mine, and the other near the northeast end, known as the Jones mine. Owing to the slight demand for this mineral, there is no systematic mining carried on. Men and children are paid a certain price per pound for the zircon crystals, some of which they wash out of the soil, others out of the kaolinized gangue, and still others they break out by hand from the harder feldspar. The resulting product contains practically 100 per cent of zircon.

There are a number of minerals associated with zircon in these pegmatites, among which are many of those carrying rare earths; as, xanthitane in abundance, with some titanite, titaniferous garnet, polycrase, allanite, auerlite,[1] monazite, xenotime, and cyrtolite. Other minerals are orthoclase in crystals, epidote, staurolite, stilbite, magnetite, apatite, quartz, muscovite, kaolin, and decomposed hydrated mica.

The discovery of these deposits of zircon was largely due to the efforts of Mr. W. E. Hidden. The first actual discovery of zircon at the locality was in 1869, but no special importance was attached to it until early in the eighties, when a demand was created for the mineral in connection with the demand for zirconia to be used in the manufacture of mantles for incandescent lights. The first shipment of zircon from the locality was in 1888. Although the shipments of zircon from this locality were never very large, they supplied the necessary material for the manufacture of the mantles referred to. With the introduction of thoria as the principal rare earth in the mantles, the demand for zirconia declined, and in a few years the production from North Carolina ceased.

[1]This is a thoria mineral; see page 30 under *Sources of Supply of Thoria.*

The production of zircon was not renewed at this locality until the introduction of the Nernst lamp, when again this locality was looked to as a source of zirconia. Shipments began in 1902 and have continued to the present time, although in no one year has there ever been any very large production.

It is of interest to note that in 1911, Mr. Hidden again became interested in the production of zircon from this locality, and reopened the old Freeman mine, which had not been operated for 24 years. He has introduced the hydraulic methods for obtaining the zircons, and a new ditch 6,000 feet long with trestles and flumes was constructed to bring water for hydraulicing the decomposed pegmatite matrix. In connection with this work Mr. Hidden is also making a special effort to obtain the auerlite as a by-product.

Zircon from Ashland, Virginia

Recently a new occurrence of zircon has been described from near Ashland, Va.[1] It was first noticed in 1910, when Mr. August Meyer of Richmond, Va., submitted a sample of sandstone, obtained on the farm of Mr. F. B. Shelton, about 3 miles west of Ashland, which he thought contained rutile. It was found to be composed of very small grains of ilmenite and zircon, together with a few grains of other minerals, chiefly quartz and silicates, cemented with limonite. It outcrops in the form of irregular flat fragments, lying loose upon the surface along a low ridge in a general direction of N. 20° E. At the point where the sandstone seems to be the most abundant and richest in zircon, the ridge marks the western edge of the Calvert formation, which is the lowest of the Chesapeake group (Miocene). The hard lumps of sandstone probably represent the local cementation of a sandy bed which, in most places, is soft or but slightly consolidated, a characteristic of the Chesapeake group (Miocene). Partly or wholly indurated sands, yielding somewhat highly ferruginous crusts and beds of sandstone, are common in the formations of the Virginia coastal plain near its western margin. So far as the authors are aware these ferruginous sandstones have been generally regarded as composed chiefly of quartz grains cemented by iron oxide. At no point beyond the Ashland area, so far as known, have they been tested for zircon or other uncommon heavy minerals.

At the home of Mr. Benjamin Wright, three-eights of a mile southwest of this locality, a highly zirconiferous and but slightly consolidated sand bed was cut in the lower part of a well 14 feet deep. This bed is

[1] Thomas L. Watson and Frank L. Hess, University of Virginia Publications; Bull. of the Phil. Soc., Scien. Section, Vol. I, No. 11, pp. 267-292, 1912.

probably the one from which the indurated fragments of zirconiferous sandstone have come. Perfectly rounded water-worn quartz and quartzite pebbles, mostly quartz, up to 3 inches in diameter and usually white, were taken from this well. None of the zirconiferous material was found south of Mr. Wright's well, and decomposed granite is exposed in a road 200 yards southwest of his house.

A hundred yards northwest of Mr. Shelton's house a bed of zirconiferous sand, similar to that cut in the Wright well, was exposed in a shallow prospect-hole. The zirconiferous sand was 18 inches thick and was underlain by clay and covered by a few inches of soil. From the appearance of the float and the sand cut in the prospect-hole, the zirconiferous bed is thought to be probably not more than 2 to 3 feet thick. The data at hand indicate that it is probably a narrow lens three-eights of a mile long and of unknown but probably of less width.

Tests made to determine the percentage of zircon in the sandstone showed that it varied from 12 to approximately 30 per cent. The crystals average less than 0.5 mm. in diameter. The fineness of the zircon suggests a possible means of separating it from its associated minerals, most of which can be caught on an 80-mesh sieve, through which over 99 per cent of the zircon slips. Associated with the zircon are quartz and a variety of heavy minerals, including garnet (?), ilmenite, rutile, staurolite, cyanite, and an isotropic green mineral which has not been definitely determined but which may be pleanaste or hercynite. Occasional feldspar and pyrite were noted in several thin sections of the rock. As stated above, these are all cemented with limonite, possibly in part siliceous.

Other Zircon Localities

NORTH CAROLINA

Near Mars Hill, Madison County, N. C., zircon was found in well developed crystals associated with large masses of monazite that occur in pegmatite. See description of locality on page 47.

Near New Sterling, Iredell County, North Carolina, a great many brownish, pyramidal crystals of zircon have been found in the soil, some of which were from 1 to 3 inches in diameter. One crystal weighed about 6 ounces. The exact occurrence of these crystals has not yet been definitely determined, but thus far there has been observed no indication of them in commercial quantity.

Small quantities of zircon are found in all the monazite sand and could probably be saved as a by-product These crystals are very

minute and are transparent. The occurrence is described under monazite.[1]

OKLAHOMA

In 1907 one of the forest supervisors for the Wichita National Forest, reported the finding of zircon about seven miles northwest of Cashion, Oklahoma, in the Wichita Mountains. Zircon crystals up to three-quarters of an inch in diameter occur thickly scattered in pegmatite rock. The crystals consisted of the simple pyramid faces with the prism almost entirely lacking. Most of the crystals were of deep red-brown color, though some were yellowish, and nearly colorless. In 1908 this deposit was exploited to some extent by Messrs. C. H. Hackney & Sons of La Harpe, Kansas. Whether the mineral occurs in sufficient quantity to be of commercial value is not known, though the hand specimens examined were quite rich.[2] There has been no commercial production of zircon from this deposit.

PACIFIC SLOPE

In connection with the investigations of the United States Geological Survey of the black sands of the Pacific slope, it was observed that zircon was one of the commoner minerals found in these sands, thus indicating that it is more or less universally distributed through granitic and allied rocks. Zircon was found in samples of black sands tested from Cape Nome, Eagle River, and Yukon territory, Alaska; Maricopa and Yavapai counties, Arizona; Butte, Calaveras, Del Norte, Eldorado, Humboldt, Los Angeles, Nevada, Placer, Riverside, Sacramento, San Luis Obispo, San Manteo, Santa Barbara, Santa Cruz, Shasta, Siskiyou, Trinity, and Yuba counties, California; Chaffee, Costilla, Eagle, Huerfano, and Routt counties, Colorado; Ada, Bannock, Bingham, Blaine, Boise, Canyon, Custer, Elmore, Idaho, Lemhi, Lincoln, Nez Perce, Owyhee, Shoshone, and Washington counties, Idaho; Laporte County, Indiana; Baltimore County, Maryland; Beaverhead, Custer, Missoula, and Powell counties, Montana; Ormsby County, Nevada; Grant, Otero, and Sandoval counties, New Mexico; Lewis County, New York; Baker, Clatsop, Coos, Lincoln, Curry, Douglas, Grant, Jackson, Josephine, Lincoln, Linn, Malheur, Multhomah, Polk, Umatilla, Wasco, and Washington counties, Oregon; Lawrence County, South Dakota; Garfield, San Juan, and Uinta counties, Utah; Asotin, Chehalis, Clallam, Clarke, Douglas, Garfield, Okanogan, Pacific, Stevens, and Watson counties, Washington; Albany, Johnson, and Sweetwater counties, Wyoming.

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[1] See Occurrence of Monazite, p. 46.
[2] Min. Res. U. S. Geological Survey, on Monazite and Zircon, 1907, p. 11.

Production of Zircon

The demand for zircon is not large and it requires but a very small amount to satisfy this. In the manufacture of the Nernst lamp there is but a very small amount of zirconia needed for each lamp, so that the tonnage of zircon necessary to furnish the zirconia is comparatively small. There is given in the following table the production in North Carolina, all of which has been used in the manufacture of zirconia, which was first used in the Welsbach mantle and later in the glower for the Nernst lamp.

PRODUCTION OF ZIRCON IN NORTH CAROLINA*

Year	Pounds	Value
1902	2,000	$ 380
1903	3,000	570
1904	1,000	200
1905	8,000	1,600
1906	1,100	248
1907	204	46
1908		
1909	2,000	250
1910		
1911	3,208	802
1912		
1913		
1914		

Source of Yttria

Gadolinite.

This mineral, the chief and most abundant source of yttria and the only one which has been produced commercially, is a basic orthosilicate, composed principally of beryllium oxide (glucina), iron protoxide, and the yttrium oxides. The yttria or "gadolinite" earths are partially replaced by the oxides of cerium, lanthanum, and didymium. Many specimens show also a very small quantity of thoria (less than 1 per cent). The mineral is monoclinic, commonly prismatic and terminated by the base. The crystals are usually rough and coarse, showing no cleavage, but have a conchoidal to splintery fracture. It is brittle, with hardness of 6.5 to 7. It varies in specific gravity, according to the percentage of yttrium oxides, from 4 to 4.5. It is greenish black and sometimes brown; in thin splinters nearly transparent, and usually of a grass-green to olive-green color. Its tustre is vitreous to greasy.

There are a number of other minerals containing the yttrium oxides, but none of them that contain a high percentage of these oxides have thus far been found in sufficient quantity to be of commercial value. The following is a list of the principal yttrium minerals:

*This also represents the production of zircon in the United States.

List of Principal Yttrium Minerals

Yttrocerite. A fluoride of calcium, with the metals of the cerium and yttrium groups, which has been found sparingly at Amity, Orange County, N. Y., and at Mount Mica, near Paris, Me. This mineral contains about 14.8 per cent of yttria oxide and 9.3 per cent of cerium oxide.

Tengerite. A hydrous yttrium carbonate, with something of a chalk-like appearance, which occurs as thin coating on gadolinite at Ytterby, Sweden, and in Llano County, Tex.

Cappelenite. This mineral is a borosilicate of yttrium and barium, with smaller quantities of cerium, lanthanum, and thorium oxides. It crystallizes in the hexagonal system in thick prisms, and has a conchoidal fracture. Its color is a greenish brown, and it has a vitreous to greasy lustre. This mineral has not thus far been identified in the United States, but has been found sparingly in Lille Arö, on the Langesund Fiord, in southern Norway.

Gadolinite. As described above.

Yttrialite. This is an amorphous mineral whose chemical composition is chiefly a silicate of thorium and the yttrium oxides, with smaller quantities of cerium, lanthanum, and didymium oxides. The percentage of yttrium oxides is 46.50, and of the thorium oxide 12 per cent. It has a vitreous to greasy lustre, and in color on a fresh fracture it is olive green, approaching drab. On the exterior surfaces it is usually altered to orange yellow. It occurs associated with gadolinite at the Llano County, Texas, locality, and is often found implanted upon it. When first found this mineral was called green gadolinite, but its true character was determined by Messrs. W. E. Hidden and J. B. Mackintosh, who gave it the name yttrialite. It has been found at this locality in masses of considerable size, one piece weighing approximately 10 pounds.

Allanite. This mineral occurs quite commonly in the pegmatitic dikes throughout the United States, and in some localities it has been found in some considerable quantity. It is a silicate of calcium, aluminum, and iron with the rare earth oxides, cerium, lanthanum, and didymium and smaller quantities of the yttrium oxides. The cerium oxides run up as high as 27 per cent, while the yttria oxides are usually less than 3 per cent. No commercial value at the present time is attached to this mineral. Allanite is a pitch brown to black mineral with a submetallic to pitchy or resinous lustre, and occurs sometimes in well developed monoclinic crystals and also massive and in embedded, angular, or rounded grains. In the pegmatitic dikes of Massachusetts, Connecticut, Virginia, North Carolina, and Colorado allanite is a rather commonly associated mineral.

Cenosite. This mineral is a hydrous calcium-yttrium silicate and carbonate containing about 37.6 per cent of yttrium oxides. It is a mineral of a yellowish brown color and greasy lustre, which is thus far known only in the single specimen that was found on the island of Hitterö, Norway.

Rowlandite. This is an yttrium silicate that occurs in massive form associated with the gadolinite of Llano County, Texas. It occurs but sparingly and is of a pale drab-green color when pure, but alters to a waxy, brick-red mineral. An analysis gave 61.9 per cent of the yttrium oxides.

Fergusonite. This mineral is essentially a meta-niobate and tantalate of yttrium with cerium, uranium, etc. The percentage of yttrium oxides varies from about 18 to 26 per cent. It is a mineral with a rather characteristic brownish-black to liver-brown color and a rather dull lustre. Its specific gravity is high, being 5.8. It usually occurs massive, but occasionally well developed tetragonal crystals have been observed. It has been found at a number of localities either in granite, or in pegmatitic dikes, as in granite at Rockport, Mass., and Amelia, Va., and in the pegmatitic dikes of Madison and Mitchell counties, N. C., and associated with gadolinite in Llano County, Texas. At this latter locality it has been found in masses weighing over a pound.

Kochelite. This mineral has been found on crystals of fergusonite from near Schreiberhau, in Silesia, as a brownish yellow to honey yellow incrustation, which showed some crystallization. This material, upon analysis, was found to be near fergusonite in composition and to contain 1.23 per cent of thoria, 12.81 per cent zirconia, and 17.22 per cent yttria. Its exact composition has not been determined. It has not thus far been identified in the United States.

Yttrotantalite. This mineral is essentially a tantalate and niobate of iron, calcium, and the rare earth oxides, yttrium, erbium, cerium, and uranium. The yttria contents of this mineral vary from about 10 to 19 per cent. It is of a black to brownish yellow color with a submetallic to vitreous lustre, and has a specific gravity of about 5.8. It has been found in but small quantity at Ytterby, Sweden.

Samarskite. This mineral is one of the more abundant minerals containing the rare earth oxides, very large quantities of it being found at the Wiseman mine in Mitchell County, N. C. It is essentially a niobate and tantalate of iron and calcium with the cerium and yttrium metals, together with uranium oxide. The yttrium oxides vary from 6 to 15 per cent, and the cerium oxides from about 2 to 6 per cent. The color of samarskite is velvet black, and its lustre varies from vitreous to resinous and splendent. It is commonly found massive or in flattened,

embedded grains, but occasionally in fairly well developed prismatic rhombohedral crystals. Its usual occurrence is in pegmatitic dikes, and the most noted locality is the Wiseman mica mine in Mitchell County, N. C., where it has been found in masses over 20 pounds in weight. At other mica mines in North Carolina it has been found more sparingly.

Euxenite. This is a niobate and titanate of yttrium, erbium, cerium, and uranium, which occurs commonly massive and is of a brownish black color. It has a brilliant to sometimes greasy lustre. It has been found at Jölster, Norway, but has not thus far been identified in the United States, unless one of the alteration products of samarskite found at the Wiseman mine in Mitchell County, N. C., can be referred to this mineral.

Polycrase. This mineral is principally a niobate and titanate of yttrium, erbium, cerium, and uranium similar to euxenite. Its yttrium oxide contents vary from 13 to 27 per cent. It is found usually in orthorhombic, prismatic crystals, which have a conchoidal fracture. It is black in color and of a vitreous to resinous lustre. It has been found in the United States near Zirconia, Henderson County, N. C., and in South Carolina about 4 miles from Marietta, Greenville County.

Yttrochrasite.[1] This is a hydrous yttrium-thorium-titanate mineral, described in 1907 by W. E. Hidden and C. H. Warren. It was found in Burnett County, Texas, near the Colorado River, associated with pegmatite by J. J. Barringer, who was looking for gadolinite. The mineral crystallizes in the orthorhombic system, and is similar in its habits to yttrotantalite. The fresh material on the inside of the crystals is of a nearly black color, but on the partially altered faces or masses it is brownish, not unlike that of polycrase and euxenite. In hardness it is 5.5 to 6; has a specific gravity of 4.80. The mineral contains 8.75 per cent of thoria and 25.67 of $(Y, Er)_2O_3$, and is represented by the formula CaO, $3(Y, Er)_2O_3$, ThO_2, $16TiO_2$, $6H_2O$. Part of the titanium is replaced by oxides of tungsten and uranium. Part of the yttrium is replaced by cerium and ferric iron. Part of the thorium is replaced by uranium. Part of the calcium is replaced by manganese and lead. Found in Texas, but not in any considerable quantity.

Of the minerals mentioned above those like samarskite and fergusonite, which occur in sufficient quantity to give any promise of being utilized commercially, are much harder to reduce than the corresponding yttrium silicates.

Occurrence of Gadolinite

Gadolinite occurs principally in pegmatitic dikes and is often associated with allanite and other minerals containing the rare earth oxides.

[1]Zeits. für Krystallographie, Vol. XLIII, p. 18, 1907.

The first discovery of this mineral in the United States was at Devils Head Mountain, Douglas County, Colo., and was described and analyzed by Mr. L. G. Eakins,[1] of the United States Geological Survey. Only a small quantity of this mineral was obtained from Colorado.

The only other locality in the United States where gadolinite is known positively to occur is in Llano County, Tex., at Barringer Hill, five miles south of Bluffton, on the west bank of the Colorado. The mineral has been found here in considerable quantity in a pegmatitic dike associated with allanite, yttrialite, nivenite, fergusonite, cyrtolite, gummite, fluorite, molybdenite, and a number of other minerals. The rocks of this district are Pre-Cambrian, occasionally capped with limestone, The granite is of various shades of color and texture, of which the most abundant is a cross-grained, deep-red granite, penetrating through which are numerous and rather extensive pegmatitic dikes exposed on the surface, and, according to Mr. Hidden, it is only in these veins or dikes that the yttria minerals have been found. The larger masses of the gadolinite have been found in the wider portions of the veins, which in some instances are seen at the present time as permanent uplifts, or mound-like elevations, and which, 100 to 150 feet in area, rise conspicuously from the surrounding country to elevations of from 25 to 30 feet. The principal one of these mounds is Barringer Hill, which has been the scene of the principal exploration. This mound is nearly circular in form, and its contact with the granite is sharply defined. The extensions of the pegmatitic dike, of which it is a part, can readily be traced in a southwesterly direction for some distance. Some of the largest masses of gadolinite known have been obtained from this locality.

The first specimen of gadolinite (about 1½ pounds) was discovered by Mr. J. J. Barringer[2] in July, 1886. A black mineral was noticed projecting from an outcrop of pegmatite, and on account of its peculiar appearance and weight, it was broken out and preserved. Upon further investigation Mr. Barringer unearthed a bunch of huge crystals or a mass of gadolinite that aggregated not less than 500 kilos. This quantity was obtained by simply digging with a pick and shovel in the partly decomposed pegmatite, and came from a space not over 4 feet deep, 3 feet wide, and 8 feet long. This mineral was not recognized when first discovered, and was known locally as "tin-stone," "blackjack," and "volcanic glass." It was also mistaken for samarskite, and was known by this name until August, 1888, when Mr. Barringer sent a specimen of it to New York in order to obtain a market for it as samarskite, and its true character was discovered. On account of the variety of minerals

[1]Proc. Colorado Sci. Soc., Vol. II, pt. 1, 1885, p. 32.
[2]Am. Jour. Sci. 3d ser., Vol. XXXVIII, 1889, pp. 474-486, and Univ. of Texas Min. Survey, Bull. No. 5, 1902, p 31.

containing the rare earths found at this locality, the property was purchased about 1888 by Mr. W. E. Hidden, of Newark, N. J., and others, and considerable work was done in order to obtain the rare earth minerals. During the investigations of Mr. Hidden and Mr. J. B. Mackintosh, several new mineral species were discovered at this Llano County locality, and the results of the investigations have been described in a paper entitled "A Description of Several Yttria and Thoria Minerals from Llano County, Texas."[1] The list of species recognized in this locality by the authors includes, "quartz, hyalite, orthoclase, albite, biotite, muscovite, magnetite, martite, gadolinite (several varieties due to alteration), fergusonite (three varieties of hydrous species), allanite, rowlandite, molybdenite, molybdite, cyrtolite (several varieties), fluorite, gummite (two varieties), a carbonate of the rare earths (tengerite?), nivenite, a hydrated thorium-yttrium-lead uranate, a hydrous uranium-thorosilicate, an yttrium-thorium silicate, and a fetid gaseous compound."

In addition to the minerals mentioned, yttrialite, rowlandite, thorogummite, mackintoshite, microcline, lithia mica, hematite, ilmenite, rutile, autunite, lanthanite, chalcopyrite, pyrite, sphalerite and powellite have been identified at this locality.

In 1901, when a commercial demand arose for yttria, the first place investigated for a commercial supply of this oxide was the Llano deposit which has continued since that time to supply the demand. About 1902, this property was acquired by the Nernst Lamp Company of Pittsburgh, Pa., and has been operated since for gadolinite, the yttria of which has been used in the manufacture of the Nernst lamp, mentioned above.

The work has been in charge of Mr. W. E. Hidden,[2] and during the winter of 1902-1903 some notable discoveries were made in the rare earth minerals at this locality. One was a double crystal of gadolinite that weighed 73 lbs., and another an 18-lb. mass of yttrialite. Also a mass of pure allanite that weighed more than 300 lbs.; about 50 lbs. of thorogummite, some pieces weighing a pound and some being in good crystals; pure masses and large aggregations of fergusonite up to 5 lbs. in weight; and a pure mass of rowlandite that weighed 2 lbs. During the four months that the mine was in operation there were sufficient yttria ores taken out for the company's needs for the rest of the year. The work was continued during the winter of 1903 and 1904, and about 1,000 lbs. of very pure gadolinite were taken out, the largest mass of this mineral that was found being a roughly crystallized mass 36 inches long and 11 inches thick at the widest part, and weighed a little over 200 lbs. It

[1] Am. Jour. Sci. 3d ser., Vol. XXXVIII, 1889, pp. 474-486.
[2] For detailed description of the results of this work see Am. Jour. Sci., 4th ser., Vol. 19, 1905, pp. 425-433.

was very pure, having a specific gravity of 4.28. Other finds during this winter's work were nearly a pound of very pure nivenite, about an ounce of mackintoshite, and a considerable quantity of cyrtolite, fergusonite, and thoro-gummite.

As a few hundred pounds of gadolinite will supply the quantity of yttria required for commercial purposes, it is necessary to work the property but a few months to obtain a year's supply of the raw material. Mr. Hidden has been in charge of the exploration and development work and, while producing gadolinite for commercial purposes, has kept a close watch on the associated minerals; and to him science is indebted for the description and information regarding the wonderful list of rare earth minerals that have been obtained from this locality.

Chemical Composition

The yttria content of gadolinite varies considerably, the lowest percentage recorded being that of a variety from Douglas County, Colo., which gave 0.22 and 0.24 per cent, while the highest was a variety from Ytterby, near Stockholm, Sweden, which contained 47.06 per cent. Both the Colorado and the Texas gadolinites have been analyzed, and in the following table are given several analyses of different specimens from each of these localities. Analyses I, II, and III are of the Llano County, Texas, gadolinite, the first two having been made by Mr. F. A. Genth[1] and the third by Mr. L. G. Eakins.[2] Analyses III and IV of the Colorado gadolinite were by Mr. L. G. Eakins.[3]

Analyses of Gadolinite from Llano County, Tex.

	I	II	III
SiO_2	22.87	22.80	23.79
Al_2O_3–F_2O_3	.28	.31	.96
Ce_2O_3	2.65	2.66	2.62
$(Di, La)_2O_3$	5.22	5.01	5.22
$(Y, Er)_2O_3$	44.35	44.45	41.55
MnO	.22	.18	Trace.
FeO	13.69	12.93	12.42
BeO	9.24	9.19	11.33
MgO	.07	.11	Trace.
CaO	.64	.71	.74
Na_2O	.20	.23	Trace.
K_2O	.15	.12	Trace.
ThO_2	----------	----------	.58
P_2O_5	----------	----------	.05
H_2O	.72	.79	1.03
Insoluble	Not det.	.93	----------
Total	100.30	100.42	100.29
Specific gravity	4.201	4.254	4.329

[1]Am. Jour. Sci., Vol. XXXVIII, 1889, p. 200.
[2]Am. Jour. Sci., Vol. XXXVIII, 1889, p. 479.
[3]Proc. Colorado Sci. Soc., Vol. II, pt. 1, 1885, p. 32, and Dana's Mineralogy, 6th ed., 1892, p. 511.

Analyses of Gadolinite from Douglas County, Colo.

	III	IV
SiO_2	22.13	21.86
ThO_2	.89	.81
Y_2O_3	22.24	28.43
Ce_2O_3	11.10	6.87
$(Di, La)_2O_3$	21.23	19.10
Fe_2O_3	3.47	4.13
FeO	10.43	11.47
BeO	7.19	5.46
CaO	.48	.63
Na_2O	.46	.52
H_2O	.86	.74
Total	100.48	100.02
Specific gravity	4.56	4.59

As is seen from these analyses, the Texas gadolinite contains a considerably higher percentage of yttria than the Colorado, which, on the other hand, is much higher in its percentage of cerium, lanthanum, and didymium oxides. Although the Nernst glower contains principally the oxides of yttrium and zirconium, it also contains very small amounts of erbium, cerium, uranium, thorium, and perhaps others of the rare earths.

Production of Gadolinite

The production of gadolinite, which has been the source of the yttria used in the manufacture of the Nernst glower, has been even smaller than the production of zircon. The average yearly production of this mineral would only be a few pounds. Thus far, none has been found in North Carolina, and while other yttria-bearing minerals have been found in the State none have been thus far produced on a commercial scale.

MONAZITE[1]

Monazite was formerly considered a rare mineral, without particular economic interest; but about 1886 a demand for thoria to be used in the manufacture of mantles for incandescent lamps, led to the exploitation of monazite as a source of supply. As a consequence, commercial deposits were found; and many localities were discovered where the mineral occurred in small quantities, or as an accessory ingredient of rocks.

Monazite is essentially an anhydrous phosphate of cerium, lanthanum, and didymium, (Ce, La, Di) PO_4, nearly always accompanied by a small percentage of thoria (ThO_2) and silicic acid (SiO_2), which are very probably united as thorium silicate ($ThSiO_4$). Some monazites

[1]Pratt and Sterrett, Monazite and Monazite Mining in the Carolinas. Trans. Am. Inst. Min. Eng. Vol. 40, 1910, pp. 313-340; Pratt, U. S. Geolog. Survey Min. Res. 1901 to 1905; Sterrett, ibid., 1906-1912; Nitze., N. C. Geolog. Survey Bull. 9, 1895.

contain but a fraction of one per cent of thoria, and one from Cleveland County, N. C.,[1] has been analyzed that showed none; others have been recorded that showed the presence of 18 to 32 per cent; but the majority contain from 3 to 9 per cent of this oxide. It is the presence of the thorium oxide that gives the monazite its commercial value. The analysis occasionally shows also the presence of other constituents, as the yttrium and erbium oxides, zirconia, alumina, magnesia, lime, and the oxides of iron, manganese, and titanium.

Monazite is light yellow, honey yellow, reddish, brownish, or greenish yellow in color, with a resinous to vitreous lustre, and is translucent to subtransparent. It is brittle with a conchoidal to uneven fracture, and is from 5 to 5.5 in hardness. It crystallizes in the monoclinic system, and some crystals have been observed that were 2 inches in length. The more perfect crystals are, however, very small, ranging from an eighth to a sixteenth of an inch in length down to microscopic ones.

The mineral is usually readily recognized after a few samples have been examined. Its color, usually yellowish, inclined to reddish, its hardness 5 to 5.5, being readily scratched by feldspar (hardness 6) or quartz (hardness 7), and its high specific gravity, 4.64 to 5.3, are the chief macroscopic properties that will aid in distinguishing it. The principal chemical and blowpipe reactions that can be readily employed to identify monazite are the following: It is incompletely soluble in hydrochloric acid, but is completely and readily acted upon by sulphuric acid. If oxalic acid is added to the very dilute filtered sulphuric acid solution, or to the solution obtained by fusing the mineral with soda, and if the mass be treated with water and the residue filtered and dissolved with hydrochloric acid, a precipitate is obtained which upon ignition becomes brick red, due to cerium oxide. Before the blowpipe the mineral turns gray, but is infusible. If heated with sulphuric acid, it colors the flame bluish green, due to phosphoric acid.

The following analyses of the mineral monazite will give a good idea of its chemical composition:

Locality	Specific Gravity	P_2O_5	Ce_2O_3	La_2O_3 Di_2O_3	$(Y,Er)_2O_3$	SiO_2	ThO_2
Amelia County, Va.[2]		24.04	16.30	34.70	1.10	2.70	18.60
Amelia County, Va.[2]	5.30	26.12	29.89	26.66		2.85	14.23
Portland, Conn.[2]	5.22	28.18	33.54	28.33		1.67	8.25
Burke County, N. C.[2]	5.10	29.28	31.38	30.88		1.40	6.49
Alexander County, N. C.[3]	5.20	29.32	37.26	31.60		0.32	1.48
Madison County, N. C.							5.00

[1]Reported to the author by Mr. Wm. E. Hidden of Newark, N. J.
[2]Analyst, S. L. Penfield, Amer. Jour. Sci., Vol. XXIV, 1882, p. 250.
[3]Analyst, Penfield & Sperry, Amer. Jour. Sci., Vol. XXXVI, 1888, p. 322.

The monazite sand as it is concentrated from the alluvial deposits, is a mixture of monazite, zircon, magnetite, ilmenite and garnet. A good many of these samples of sand containing approximately 50 to 60 per cent of monazite and in the condition that they are sold to the concentrating mills, have been analyzed for their thoria content, with the following results:

PERCENTAGE OF THORIA (ThO_2) IN NORTH CAROLINA MONAZITE SANDS

	Locality	ThO_2 Per Cent
1	White Bank Gold Mine, Burke County	2.15
2	Hall Creek, Burke County	2.25
3	Linebacher Place, Silver Creek, Burke County	6.54
4	Long Branch, McDowell County	1.27
5	Alexander Branch, McDowell County	6.30
6	MacLewrath Branch, McDowell County	2.48
7	Proctor Farm, near Bellwood, Cleveland County	5.87
8	Wade McCurd Farm, Carpenter's Knob, Cleveland County	6.26
9	Davis Mine, near Mooresboro, Cleveland County	3.98
10	Henrietta, Rutherford County	1.93

In the concentrating mills the monazite is almost completely separated from its impurities, so that the thoria content is raised approximately 30 per cent.

Samples of monazite sands from Big Hole River and Beaver Head County, Montana, which contained 65 per cent of monazite have been assayed by Dr. Chase Palmer of the United States Geological Survey, and found to contain 1.69 per cent of thoria, which would be equivalent to about 2.6 per cent in the pure monazite.

Other Minerals Containing Thoria

There are several other minerals that contain thoria, but it was not until 1905 that any of them were found in sufficient quantity to make them of interest commercially. Thorite and thorianite are now known to be in commercial quantity in Ceylon. Monazite, however, still continues to be the chief source of supply of thoria.

Thorianite. An interesting mineral, thorianite, was dicovered early in 1904, associated with corundum, zircon, tin, topaz, spinel, etc. The mineral was first found by Mr. W. D. Holland in the refuse from gem washing near Balangoda, Ceylon, and was supposed to be uraninite or pitchblende, but upon analysis it was found to contain a very large percentage of thoria. The analysis of the mineral is as follows:[1]

[1]Dunstan, Wyndham R., Ceylon Mineral Survey, No. III; Mining Engineering (London), March 1905, and Min. Mag., May, 1905.

ANALYSIS OF THORIANITE

Thorium oxide	76.22
Cerium, lanthanum, and didymium oxides	8.04
Zirconium oxide	Trace
Uranium oxide	12.33
Ferric oxide	.35
Lead oxide	2.87
Silica	.12
	99.93

The thoria varies in the different analyses from 70 to nearly 80 per cent. No definite formula has been worked out for this mineral, and it is thought to be a mixture of the oxides of thorium and uranium. The thorianite occurs in cubical crystals, sometimes twinned, which have a jet black color. On worn surfaces the color is dull gray or brownish black. Its lustre is resinous to submetallic; and it is brittle and breaks with an uneven to conchoidal fracture. In hardness it is 5.5 to 6.

The specific gravity of the mineral is given as 9.32, and it was observed in black, cubical crystals, which are fairly hard and give a brown streak. According to Mr. W. F. Petterd,[1] the powdered thorianite dissolves readily in dilute sulphuric as well as in nitric acid. It has also been shown to be highly radioactive because of its uranium content.

In August, 1905, the Ceylon variety was discovered in its matrix, which was a weathered pegmatite in which kaolin and hydrated mica were the chief constituents. A commercial test was made to determine the amount of thorianite in the rock, and it was found to contain six pounds of this mineral per ton of the rock as mined. Thorite has also been found associated with the thorianite in the pegmatite.

Thorianite was discovered in 1907 in black sand concentrates obtained from the vicinity of Norris, Montana.[2] These concentrates were examined by Mr. Wirt Tassin of the United States National Museum, who reported them to contain considerable magnetite, ilmenite with xenotime, zircon, garnet, quartz, ruby spinel (sparingly), monazite, and thorianite. The thorium content of these concentrates is very low. This is the first discovery of the thorium mineral, thorianite, in the United States.

Thorite. Another mineral that contains a high percentage of thoria is thorite, an orthosilicate of thorium ($ThSiO_4$). The theoretical percentage of thoria in this mineral is 81.5, but usually it does not exceed 70 per cent. The pure orange colored variety, containing the higher percentage of thoria, is known as orangite, and it has a specific gravity of 5.4 as compared with 4.5 for the ordinary thorite. The mineral

[1] Min. World, Sept. 16, 1905.
[2] U. S. Geolog. Survey, Min. Res., 1907, p. 791.

crystallizes in the tetragonal system, the crystals being similar to the simple zircon crystals consisting of prism and pyramid. In color the mineral varies from orange yellow and brownish yellow of the pure varieties to black inclining to brownish of ordinary thorite. It is subtransparent to opaque with a vitreous to resinous lustre, and varies in hardness from 4.5 to 5.

All the analyses of thorite show water and sometimes uranium. The thorium content in the analyses examined varies from 48.66 to 71.65, and the uranium content from 1.13 to 9.96. The water varied from 6.14 to 11.31.

This mineral has been found in commercial quantity in Ceylon,[1] has been mined to some extent, and a part of the production exported.

It has been found sparingly in the United States at one locality in New York State[2] and in the granite of the Trotter Mine,[3] Franklin Furnance, New Jersey. The general occurrence of this mineral seems to be in pegmatite or granitic rocks. There is one mineral which occurs in the United States in some quantity that approaches the thorite in composition and crystallization, and that is the mineral auerlite that is found associated with the zircon at the Freeman Mine, Henderson County, North Carolina, and which is described above.

There are several other minerals that contain thoria, but only one or two of them contain a sufficiently high percentage to make them worthy of consideration as a possible commercial source of supply of this oxide.

Auerlite. This mineral crystallizes in the tetragonal system, the crystals forming a square prism terminated with a pyramid, resembling zircon in habit and angles. In color it is dull yellowish white to orange-red, and has a resinous lustre. It is only 2.5 to 3 in hardness, and has a specific gravity of 4.42 to 4.77. The mineral is of especial interest on account of its high percentage of thoria, 70.13. The mineral was discovered at the Freeman Zircon Mine by Mr. W. E. Hidden and J. B. Mackintosh.[4] An analysis of the mineral gave the following: SiO_2, 7.62; P_2O_5, 7.46; ThO_2, 10.13; (H_2O, CO_2), 11.21; Fe_2O_3, 1.38; CaO, 0.49; MgO, 0.29; Al_2O_3, 1.10.

The mineral is more or less altered, so that it cannot be definitely determined just what its composition may be. It is evidently a hydrous thorium silicate, with perhaps a small amount of thorium phosphate. The mineral is closely associated with zircon and xenotime, and there has been observed parallel intergrowths of auerlite with these minerals. When heated before the blowpipe auerlite becomes brown; but turns orange again on cooling.

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[1]U. S. Geolog. Survey, Min. Res., 1907, p. 791-2.
[2]Dana Mineralogy, 6th Edition, p. 489, 1892.
[3]Transactions New York Acad. Sci., Vol. XIII, p. 76, 1893.
[4]Amer. Jour. Sci., Vol. 36, p. 461, 1888.

While Mr. W. E. Hidden was working the Freeman zircon mine near Zirconia, Henderson County, North Carolina, he made a special effort to separate and save the auerlite from the zircon, and during the brief operations of this mine during 1912, he obtained one kilogram of auerlite. Mr. Hidden hopes, during the future development of this property, to be able to produce sufficient auerlite to make it a commercial source of thoria. Thus far auerlite has only been found at the Henderson County zircon mine.

Allanite (Orthite). For description see under *Yttrium Minerals.*

Tscheffkinite. This is a massive amorphous mineral, velvet black in color, and with a vitreous lustre. Its composition is uncertain, and it is believed that it is an alteration product. It might be related to keilhauite. It is a titanosilicate of calcium and ferrous iron, the yttria and cerium groups of metals. It was first found in the Ilmen Mountains in the Ural. It has been identified in the United States in only one State, Virginia,[1] where it was first found on Hat Creek, near Massey's Mills, Nelson County. A mass weighing 20 pounds was picked up here which on analysis was found to contain 2.29 per cent thoria. It has also been found in Bedford County to the south, where it is reported to be in some quantity. Analysis of samples from this locality only gave 0.75 to 0.85 per cent. The Ural variety is reported as containing 20.91 per cent thoria.

Pyrochlore. The common occurrence of pyrochlore is in octahedral crystals, which break with a conchoidal fracture. The mineral is brittle with a hardness of 5.5 and a specific gravity of 4.32. It has a vitreous to resinous lustre, and varies in color from a dark reddish to blackish brown. In composition it is chiefly a niobate of the cerium metals, calcium and sodium, and with titanium and fluorine. The thoria content varies from 4.96 to 7.56 per cent. This mineral has only been reported from one locality in the United States—from St. Peter's dump, Pike's Peak, Colorado, where it occurs with zircon in syenite.[2]

Fergusonite. Thoria to the amount of 2 per cent has been reported to have been found in fergusonite, associated with thorianite in Ceylon.

For description of this mineral see yttrium minerals. Analyses of fergusonite from most of the American localities do not show any thoria, but the Llano County, Texas, fergusonite contains from 0.83 to 3.38 per cent of thoria.[3]

Kochelite. For description of this mineral see yttrium minerals. It only contains 1.23 per cent thoria, and is, therefore, of no interest as a commercial source of this oxide.

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[1]Amer. Chem. Jour., Vol. X, p. 38, 1888. Amer. Jour. Sci., Vol. XLII, p. 36, 1891. Dana Mineralogy, 6th Edition, p. 718, 1892.
[2]Dana's Mineralogy, 6th Edition, p. 727, 1892.
[3]Amer. Jour. Sci., Vol. XXXVIII, p. 482, 1889.

Zirkelite. For description of this mineral see zirconium minerals. Analyses show this mineral to contain 7.31 per cent of thoria. It has not thus far been found in the United States.

Uraninite. This mineral usually occurs massive and botryoidal, but is occasionally in octahedral crystals. It has a submetallic to greasy or pitch-like lustre, and is often known as pitchblende. In color, it is from greenish to brownish to velvet black. It is 5.5 in hardness, and, when pure, has a specific gravity of 9 to 9.7. This mineral alters rather readily to gummite, so that very often the uraninite is found enclosed by a coating of the orange-red gummite. In composition it is a uranate of uranyl, lead, with usually thorium and the metals of the lanthanum and yttrium groups. Nearly all analyses show the presence of thoria, which varies from 1.65 to 9.79 per cent.

Thorogummite.[1] This mineral occurs massive, associated with zircon and fergusonite at the gadolinite locality in Llano, Texas. It has a dull yellowish brown color, which changes upon ignition to a dull greenish hue. It has a hardness of 4 to 4.5, and a specific gravity of 4.43 to 4.45.

In composition the mineral is a hydrous uranate of thorium and silicon, with lead, cerium and yttrium silicate, containing 41.44 per cent thoria.

Chlorothorite is the name given provisionally by W. E. Hidden to a tetragonal thorium silico-uranate, which is similar in composition to the thorogummite.

Yttrochrasite. This is a yttrium-thorium-urantitanate. See description of mineral under yttria minerals, page 22.

Uses of Monazite

Source of Thoria and Ceria

The commercial use of monazite is as a source of thoria and ceria, which are used in the manufacture of mantles for incandescent lighting.

Soon after the first mantles for incandescent lighting were manufactured, principally of zirconia, experiments were made to obtain some other earth oxide that would give more satisfactory results. It was soon discovered that thoria increased the strength of the mantle, and also its brilliancy. Auer von Welsbach patented the thoria mantle in 1886. But further experiments soon proved that it was the very small amount of ceria mixed with the thorium oxide that gave the best results in the mantles. Since that time the main object has been to use pure thorium salts and a small amount of pure ceria in the construction of the mantle. There has been little or no change in the composition of

[1] Amer. Jour. Sci., Vol. XXXVIII, p. 480, 1889.

the mantles for some years. The main advance has been in the shape of the mantle and the way it is employed, some of the best results being obtained from the inverted mantle. One advantage of the use of thoria over the other rare earth oxides is that, when the thorium nitrate is heated and converted into thorium oxide, it expands enormously, thus forming a highly spongy mass, containing an enormous number of air cells, which render it an excellent non-conductor.

The amount of ceria required to unite with the thoria to make the best mantle has been carefully ascertained by experiment, and it has been found that 99 per cent of thoria and 1 per cent of ceria gives the maximum illuminating effect.

In determining the relation between the temperature and the illumination of the flame and mantle, considerable work was done in 1900-1-2 by A. H. White, A. F. Traver, and H. Russell. It appeared from their researches that the illumination was due more to the composition of the mantle than to the temperature, and that the mantle acts as a transformer in changing the heat of the flame into light. The results of their work are summarized as follows:

> The temperature of the commercial mantle burned under usual conditions will vary from 1,500° to 1,600° C. For any single mantle the illumination will vary with the temperature. For different mantles, the illumination will depend to a greater degree upon the composition of the mantle than it will upon the temperature. The mantle with the highest temperature does not necessarily give the most light. A mechanical mixture of thorium and cerium oxides when exposed to a flame gradually increases in temperature and illumination till these approximate what would initially be shown by oxides prepared from the mixed nitrates, but the temperature remains below that which pure oxide of thorium would attain in the same flame. It is concluded that the exceptional efficiency of the mantle is due to a solid solution of the oxide of cerium in the oxide of thorium, and that this substance is capable of transforming the heat of the flame into light more economically than a black body or any other substance yet known.[1]

The Welsbach mantle consists of a cylindrical hood composed of a network of the rare earths, the top of which is drawn together and held by a loop of asbestos or platinum wire. When in use, this mantle is suspended over the flame on the principle of the Bunsen burner, in which the heating instead of the illuminating power of the hydrocarbon of the gas is used by burning it with an excess of air. In this manner the mantle becomes incandescent and glows with a brilliant and uniform light.

A short description of the method of manufacture of these mantles may be of interest. The first part of the process is the selection of the

[1] Jour. Soc. Chem. Industry, Aug. 15, 1902, pp. 1012-1017.

thread or fiber from which the mantle fabric is knitted. The fiber mostly used is cotton, either the upland, river bottom, Peeler, Allen seed, Sea Island, or Egyptian variety, the market price varying from about 10 cents for the upland to 30 cents per pound for the Egyptian. The cheaper cottons are used in the lower grade mantles, the highest grade mantle requiring the best quality of cotton. The thread is purified, so as to remove every possible trace of mineral matter. If the thread used shows a mineral impurity exceeding 0.15 per cent, it will introduce factors that will affect the physical and lighting life of the mantle. Cylinders of network of various diameters are knitted out of the thread and then washed in ammonia and distilled water and wrung out in mechanical clothes wringers. After drying, they are cut into pieces sufficiently long to make two mantles.

These knitted fabrics are then placed in a suitable vessel and covered with the "lighting fluid," in which they remain until thoroughly saturated. The excess of fluid is drawn off and the fabric put through an equalizing machine, piece by piece. The "lighting fluid" is composed of a solution of approximately 99 per cent of thorium nitrate and 1 per cent of cerium nitrate in distilled water, in the ratio of 3 parts of water to 1 part of mixed nitrates. The fabric is dried and then cut to the proper length required for a hood. It is then shaped over a wooden form and the upper end drawn together by means of an asbestos cord (occasionally of platinum). After the mantle has been modeled the cotton fiber is eliminated by heating the hood over a hot Bunsen burner flame, leaving the mantle composed of a residue of thoria and ceria. The peculiarity of these oxides is that they have sufficient cohesion to hold together during the remainder of the process of manufacture, after every bit of the supporting cotton thread has been burned away. The hood is then subjected to a series of tempering and testing heats, during which it is carefully shaped to its permanent form. In order to protect the mantle during its inspection, packing, transportation, and installation, it is dipped in collodion. Just before using the mantle this collodion covering has to be burned off.

The number of Welsbach incandescent mantles made of thoria and ceria during 1913 was 315,000,000,[1] and while the quantity of thoria and ceria used in one mantle is extremely small, yet in the aggregate it amounts to a considerable weight and requires a large tonnage of monazite and thorianite or thorite to give the amount required.

In 1902 an incandescent mantle was described[2] which was made by treating a mantle made of the oxides of thorium and cerium with silicozirconates of soda. By this treatment the inventor, Mr. R. Langhaus

[1]Chas. Baskerville, Jour. of Ind. and Eng. Chem., Vol. VI, p. 184, 1914.
[2]U. S. Cons. Rpt. 66, 1902, pp. 262-265.

claimed that an incandescent mantle was obtained that had more permanent candle-power and less tendency to shrinkage than other mantles. The life of this mantle was reckoned at from 1,800 to 2,000 hours.

This treatment of the mantles has not been used to any great extent.

It is interesting to note the difference in price of thorium nitrate when a demand arose for it commercially, as compared with the price when it was simply of scientific interest. In 1888 thorium nitrate was quoted at approximately $500 a pound. A commercial demand having arisen, and monazite having been found in commercial quantities, the price immediately began to decline; and in less than 15 years it had dropped to $5 a pound.

A certain amount of cerium, not used in the manufacture of mantles, is prepared for druggists in the form of oxalate. Another compound obtained from monazite is didymium oxide, which, being dark brown in color, is used in placing upon the mantles an indelible brand. A nitrate solution is made, and a rubber stamp is used in branding.

The Welsbach Lighting Company of Gloucester, New Jersey, was one of the largest users of monazite, and has taken a great deal of interest in the rare earth salts obtained in the decomposition of the monazite in the separation of thoria and ceria. This company has also carried on a great many experiments as to the economic use of these salts; but up to the present time there has been little or no commercial value for any except the thorium, cerium, and didymium nitrates used in the manufacture of the mantles, and the cerium oxalate sold to pharmacists.

The value of compounds of rare earths as mordants was tested by Messrs. Charles Baskerville and T. B. Foust with unfavorable results.[1]

Source of Lanthanum

Another use of certain of the rare earth metals that are found associated with thoria was exploited about 1907. It resulted from a discovery by Auer von Welsbach that certain alloys of iron with cerium, lanthanum, and other of the rare earth metals possess the property of emitting a flame of great brilliancy and with little heat and smoke when scratched with steel.[2] The sparks produced readily ignite gases, tinder, alcohol wicks and explosives. It was suggested that these alloys might be used commercially: In igniting gas lights by the friction of steel moved against the alloy by an electro-magnet; in the ignition of explosives instead of with fulminates; in photography by utilizing the flame produced instead of magnesium powders; and in military signaling.

[1] Jour. Soc. Chem. Ind., Feb., 1904, p. 104.

[2] Silberstein-Gilbert, Leo., Sci. American, Feb. 8, 1908; Advance Chapter Min. Res. U. S. Geol. Survey, 1907, p. 3.

The character of the light is said to vary with the composition of the alloy. Several of these alloys were made at Treibach, Austria, and were quoted at $6 to $7 a pound. Special names were given to them, such as: "lathan," an alloy of lanthanum and cerium with iron; "erd-metal," iron with several of the rare earth metals; and "cer," an alloy of cerium and iron. It is claimed that the intensity of the sparks and the ease with which they may be produced are greatest in alloys containing iron up to 30 per cent. The iron may be replaced in part by nickel, cobalt or manganese.

Radioactivity of Monazite

Monazite has also been tested as to its radioactivity by B. B. Boltwood of Yale University.[1] One sample was from North Carolina, which was in the form of sand and contained 5 per cent of thoria and 0.43 per cent of uranium; one from Connecticut, representing a massive specimen, which contained about 8 per cent of thoria and 0.3 per cent of uranium; a third from Norway, representing a single good-sized crystal and containing from 7 to 9 per cent of thoria and 0.41 per cent of uranium; and the fourth from Brazil, which was in the form of sand and contained about 5 per cent of thoria and 0.31 per cent of uranium. In the following table the results obtained in the examination of the monazite minerals are given, together with the results of the other minerals for comparison. Column 1 gives the activity of the emanations contained in one gram of the mineral; column 2, the activity of the emanation lost by one gram of the mineral at ordinary temperatures; column 3, the sum of the two previous activities (total emanation equivalent to the radium content in one gram of the mineral); column 4, the percentage of the total emanation lost by diffusion from the cold mineral (the emanating power of the mineral at ordinary temperatures); column 5, the weight (in grams) of the uranium content in one gram of mineral; column 6, the ratio of the radium to the uranium (the number obtained on dividing the total activity, column 3, by the quantity of uranium, column 5).

Comparative Results Obtained in the Examination of Monazite

No. of Specimen	Substance	Locality	I	II	III	IV	V	VI
1	Monazite	North Carolina	.88	.00	.88		.0043	205
2	Monazite	Connecticut	.63	.00	.63		.0030	210
3	Monazite	Norway	.84	.01	.85	1.2	.0041	207
4	Monazite	Brazil	.76	.00	.76		.0034	223

[1]Origin of Radium, by B. B. Boltwood, Philosophical Magazine, April, 1905.

From the data given in the table it is evident that a direct proportionality (within the limits of experimental error) exists between the quantities of radium and the quantities of uranium, and the inevitable and only possible conclusion is that uranium is the parent of radium. The participation by thorium in the production of radium which has been suggested by some, is entirely excluded, since the radium-uranium ratio in the thorites, containing approximately 50 per cent of thorium, is the same as that in such minerals as carnotite and uranophane, where the content of thorium is not over a few hundredths of a per cent at the highest.

One of the interesting facts brought out by Mr. Boltwood's investigations, especially as they refer to monazite, is that the thorium has apparently no participation in the production of radium and that the radioactivity of monazite is due to its uranium content.

Occurrences of Monazite

Monazite is found very widely distributed as an accessory constituent in varying proportions of many granites and their derived gneisses. Thus it has been found in the porphyritic, granulitic, and schistose gneisses of the Maritime Mountains of Brazil, extending for a distance of 300 miles through the province of Bahia, Minas-Geraes, Rio de Janeiro, and Sao Paulo;[1] and in the pegmatitic portions of the granitic mica-gneisses and hornblende-gneisses of the South Mountain region of North Carolina, covering an area of some 3,500 square miles in McDowell, Burke, Caldwell, Rutherford, Cleveland, Polk, Catawba, Iredell, Alexander, Lincoln, and Gaston counties, and extending into Spartanburg, Laurens, Greenville, Pickens, Anderson, and Oconee counties, South Carolina.[2] Although occurring in but small quantity, it has been identified in the granites or gneisses of Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, North Carolina, South Carolina, and Georgia. In North Carolina there are a number of mica-schists that carry monazite, as those near the Deake mica mine, Mitchell County, and at Milholland's mill, Alexander County.

In Idaho,[3] monazite occurs as an accessory mineral in the immense granite areas that embrace the whole upper drainage basin of Boisé and Payette rivers in the eastern portion of the State. A similar occurrence in western Montana[4] is indicated by the discovery of monazite in the sands and gravels.

It has also been found in pegmatitic dikes, where it is apt to be in large crystals, the largest that have been found being in an occurrence

[1] Amer. Jour. Sci., 3d series, Vol. XXXVII, 1889, p. 109.
[2] Bull. North Carolina Geological Survey, No. 9, p. 27.
[3] U. S. Geol. Survey 18th Ann. Rpt. Pt. 3, 1898, pp. 630-632; and Bull. No. 430, 1910.
[4] U. S. Geol. Survey, Min. Res., p. 960, 1910.

of this type. In the pegmatitic dikes of southern Norway, which have been mined for feldspar, monazite has been found in crystals and masses of size sufficient to be readily picked out by the miners while sorting the feldspar. There has probably never been more than a ton per year shipped from this locality. In a pegmatitic dike near Mars Hill, Madison County, N. C., rough crystals of monazite have been found up to 1½ inches in length. (See page 47.) Some of the masses weighed 60 pounds.

New occurrences of monazite in the eruptive granites and their derived gneisses are constantly being recorded; usually in the muscovite or biotite, not in the amphibole, varieties.

The presence of monazite or zircon is a pretty good indication of eruptive rock; hence, no matter how badly a rock may be altered, if these minerals occur in it, it may be considered to have been originally eruptive. The only occurrence recorded of monazite in a volcanic rock is a variety of this mineral that was found in a druse of a sanidine bomb near Coblenz, Prussia.[1]

There is given below a table that gives approximately the geographical localities in which monazite has been found; also the country rocks in which they occur, and the principal minerals with which they are associated.[2]

OCCURRENCES OF MONAZITE

Localities	Country Rocks	Associated Minerals
UNITED STATES.		
Maine:		
East Blue Hill	Gneiss	
New Hampshire:		
Wakefield	Gneiss	Rutile, Cassiterite (?)
Rhode Island:		
Narragansett Pier	Granite	
Westerly	Granite	
Massachusetts:		
Ayer	Gneiss	Zircon, rutile.
Westford	Gneiss	Xenotime

[1]Poggendorff, Annalen, 1871, Erg.——Bd. 5, p. 413.
[2]This is a revised table of one prepared by H. B. C. Nitze for the North Carolina Geological Survey, and published as Bull. 9, 1895.

OCCURRENCES OF MONAZITE—CONTINUED

Localities	Country Rocks	Associated Minerals
Connecticut:		
Chester	Gneiss	Sillimanite
Norwich	Gneiss	Sillimanite
Portland		
Watertown	Granite	Apatite, Tourmaline
New York:		
New Speedway, along Harlem River, New York City		Xenotime
Yorktown		Sillimanite
Virginia:		
Amelia Court House	Albitic granite	Microlite, amazonstone, beryl, apatite, orthite, columbite, manganese tantalate
North Carolina		
Alexander County:		
Hiddenite mine		Quartz, hiddenite, rutile
Millholland's Mill	Garnetiferous mica schist	Rutile
Clay County	Gravel	
Gaston County:		
Crowder's Mountain		
Jackson County:		
Horse Cove	Placer gravel	
Madison County:		
Near Mars Hill	Pegmatite	Zircon
Mecklenburg County:		
Todd's Branch	Gold placers	Garnet, zircon, diamond
Mitchell County:		
Deake Mica Mine	Pegmatite	Autunite, garnet, uraninite, gummite
Near Spruce Pine	Mica schist	
Yancey County:		
Ray Mica Mines	Pegmatite	Orthoclase and beryl
Alexander, Burke, Caldwell, Catawba, Cleveland, Gaston, Iredell, Lincoln, McDowell, Polk, Rutherford, Counties	Pegmatized gneiss and stream placers	Magnetite, ilmenite, chromite, garnet, zircon, rutile, brookite, xenotime, fergusonite, corundum, epidote, beryl, cyanite, pyrite
South Carolina		
Anderson, Cherokee, Greenville, Laurens, Oconee, Pickens, Spartanburg, Counties	Gravel and pegmatized gneiss	Magnetite, ilmenite, garnet, zircon, quartz

OCCURRENCES OF MONAZITE—Continued

Localities	Country Rocks	Associated Minerals
Georgia		
Hall County:		
"The Glades," ten miles northeast of Greenville	Placer deposits	Gold
Rabun County[1]	Placer deposits. (Monazite said to carry 4% thoria)	Gold
Indiana		
Laporte County:		
Near Michigan City	Placer deposits	Magnetite, chromite, garnet, zircon, quartz, gold
South Dakota		
Lawrence County:		
Near Tinton	Placer deposits	Magnetite, ilmenite, cassiterite, apatite, quartz
Pennington County:		
Big Horn Mountains		Magnetite, chromite, hematite, gold
Montana		
Beaverhead County:		
Trail Creek	Granite and placer deposits	
Granite County:		
Near Princeton	Placer deposits	Magnetite, ilmenite, gold, platinum
Powell County	Placer deposits	Magnetite, chromite, garnet, zircon, gold
Madison County:		
Near Norris	Placer deposits	Thorianite, xenotime, zircon, garnet, quartz, ruby spinel, gold
Nevada		
Ormsby County:		
Near Carson City	Placer deposits	Magnetite, chromite, garnet, zircon, quartz, gold
Utah		
Uinta County:		
Gesen District, Green River	Placer deposits	Magnetite, chromite, garnet, zircon, quartz, gold
Idaho[2]		
Ada, Boise, Canyon City, Idaho, Lemhi, Lincoln, Nez Perce, Owyhee, Shoshone, Meadows, Counties	Gravel and granite	Magnetite, ilmenite, garnet, zircon
Washington		
Chehalis County:		
Moclips, Gray's Harbor	Placer deposits	Magnetite, chromite, ilmenite, olivine, zircon, quartz, gold
Douglas County:		
Columbia River	Placer deposits	Magnetite, chromite, ilmenite, zircon, quartz, gold
Stevens County:		
Wilmot Bar, Columbia River	Placer deposits	Magnetite, ilmenite, garnet, zircon, quartz, gold

[1]Min. Res., U. S., Geol. Survey, 1906, p. 1196.
[2]See p. 48.

OCCURRENCES OF MONAZITE—Continued

Localities	Country Rocks	Associated Minerals
Wyoming		
Bald Mountain District	Placer deposits	Magnetite, chromite, ilmenite, garnet, olivine, zircon, quartz, gold
Colorado		
Chaffee County:		
Near Buena Vista	Placer deposits	Magnetite, ilmenite, garnet, zircon, quartz
Costilla County:		
San Lina Valley	Placer deposits	Magnetite, chromite, ilmenite, zircon
Routt County:		
Timberlake	Placer deposits	Magnetite, ilmenite, zircon, quartz, gold
Oregon		
Clatsop County:		
Near Astoria	Natural sands from bottom river	Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Clatsop Beach	Beach sand	Magnetite, chromite, garnet, zircon, quartz
Near Warrington	Sands	Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Hammond	Sand	Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Fort Stevens	Sand	Magnetite, chromite, garnet, olivine, zircon, quartz
Carnahan Station	Sand	Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Near Seaside	Sand	Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Near Gearbart Park	Sand	Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Morrison	Sand	Magnetite, chromite, garnet, olivine, zircon, quartz
Clatsop's Pit, Columbia River	River sand	Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Elk Creek	Sand	Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Coos County:		
South Fork, Coquille River	River sand	Magnetite, chromite, garnet, zircon
Randolph District	Beach sand	Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Curry County:		
Gold Beach	Beach sand	Magnetite, chromite, garnet, olivine, gold, zircon, quartz, platinum
Port Orford	Placer deposits	Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Josephine County:		
Holland		Magnetite, chromite, ilmenite, garnet, olivine, quartz, gold
Sucker Creek	Placer deposits	Magnetite, chromite, ilmenite, zircon, quartz, gold, platinum
Wolf Creek	Placer deposits	Magnetite, chromite, garnet, olivine, zircon, quartz, gold and platinum
Placer Creek	Placer deposits	Magnetite, chromite, ilmenite, zircon, quartz, gold and platinum

OCCURRENCES OF MONAZITE—CONTINUED

Localities	Country Rocks	Associated Minerals
Oregon		
Linn County:		
Foster		Magnetite, chromite, garnet, zircon and quartz
Multnomah County:		
Fulton	River sands	Magnetite, ilmenite, olivine, zircon and quartz
Near Latourville, Columbia River	River sands	Magnetite, chromite, ilmenite, garnet, olivine, zircon, gold
Polk County:		
Fall City		Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Umatilla County:		
Weston	Placer sands	Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Wallowa County:		
Near Wallowa		Magnetite, chromite, garnet, quartz, gold
Wasco County:		
Near Hood River	Beach sands	Magnetite, chromite, hematite, garnet, olivine, zircon
Near Hood River, Columbia River	River sands	Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Wheeler County:		
Antone	Placer deposits	Magnetite, chromite, ilmenite, limonite, quartz, platinum
California		
Del Norte County:		
Near Crescent City	Sands	Magnetite, chromite, garnet, olivine, zircon, quartz, gold
Nevada County:		
Rough and Ready	Placer deposits	Magnetite, chromite, ilmenite, hematite, quartz, gold
Plumas County	Placer deposits	Magnetite, chromite, ilmenite, garnet, quartz
Arizona		
Yavapai County:		
Black Canyon Creek	Placer deposits	Magnetite, garnet, hematite, quartz, gold
New Mexico		
Sierra County:		
Near Shandon	Placer deposits	Magnetite, ilmenite, hematite, quartz
CANADA		
Villeneuve Mica Mine, Ottawa County, Canada	Pegmatite	Garnet, tourmaline, uraninite
British Columbia:		
North Thompson River	Placer deposits	Magnetite, chromite, garnet, zircon, gold
Hall Creek, Nelson District	Placer sands	Magnetite, hematite, gold
Saskatchewan River	Placer sands	Magnetite, chromite, garnet, olivine, zircon, quartz, gold

OCCURRENCES OF MONAZITE—Continued

Localities	Country Rocks	Associated Minerals
SOUTH AMERICA		
United States of Columbia:		
Rio Chico, Antioquia	Gold placers	
Teragoza	Placer sands	Magnetite, chromite, ilmenite, zircon, quartz
Brazil:		
Alcobaca, Province of Bahia	Beach sands	
Caravellas, Province of Bahia	Beach sands	
Salabro, Province of Bahia	Diamond sand	Quartz, zircon, garnet, disthene, staurolite, corundum
Province of Bahia	Red syenite	
Province of Minas Geraes	Red syenite	Magnetite, ilmenite, pyrite
Province of Minas Geraes, Rio de Janeiro, and Sao Paulo	Gold placers	
Provinces of Bahia, Minas Geraes, Rio de Janeiro, and Sao Paulo	Porphyritic, granulitic and schistose gneisses, red syenite, granite dikes	Apatite, magnetite, ilmenite, rutile, garnet, zircon, sillimanite
Argentine Republic:		
Buenos Ayres	River sands	Zircon
Cordoba	Gneiss and granite	
Espirito Santo:[1]		
On the lower Rio Doce, Fazenda, Catila	Iron ore	Magnetite, ilmenite
Minas Geraes:[1]		
Jequitinhonha	With graphite	Constitutes principal portion of non-carbonaceous residuum
Rio de Janeiro:[1]		
Near Sao Fidelis	With graphite	Constitutes principal portion of non-carbonaceous residuum
ENGLAND		
Cornwall	Clay slates	Quartz, albite
SWEDEN		
Hölma		
Kararfvet	Albitic granite	Gadolinite, hjelmite, emerald
Johannisberg	Cobalt ore	
NORWAY		
Dillingso, Moss, Lönnesby, Arendal, Narestoe, Hitteroe Hvalo	Pegmatite	
Arendal and Midbö		Cryptolite in apatite
Noterö	Granite	In feldspar, enveloped by orthite
Helle		
FINNISH LAPMARK		
Ivalo	Gold sands	Zircon
RUSSIA		
Ilmen Mountains	Albitic granite	Zircon, columbite, samarskite
Sanarka River	Placers	
BELGIUM		
Nil St. Vincent		
FRANCE		
Le Puys, near St. Christophe, Dauphine		Adularia, crichtonite, sphene, anatase

[1]Orville A. Derby, Am. Jour. Sci., Vol. XIII, 1902, p. 211.

OCCURRENCES OF MONAZITE—Continued

Localities	Country Rocks	Associated Minerals
SWITZERLAND		
Binnenthal		
Olivine, near Mte. Camperio	Quartz vein, traversing mica schist	Rutile
Tessin		
Perdatsch		
Santa Brigritta, near Ruaras, Tavetsch Valley		
GERMANY		
Laacher See, near Coblenz	Druse in sanadine bomb	
AUSTRIA		
Josephinenhuette, Riesengebirge, Silesia	Pegmatite	(In black mica). Ilmenite, fergusonite, yttrium spar, zircon
Schreiberhau, Silesia		Gadolinite, yttrium spar, xenotime, fergusonite
Schuttenhofen, Bohemia	Pegmatite	Apatite
Pisek, Bohemia		In beryl and feldspar
AUSTRALIA		
New South Wales:		
Vegetable Creek, County Gough		
Richmond River[1]	Sand	
Black Swamp, near Tarkington[2]	Sand (Monazite from this sand contains 4.11%thoria)	
Queensland: [2]		
Wolfram Field, near Cairns	Sand (Monazite from this sand contains 3.90%thoria)	
SOUTH AUSTRALIA		
Kangaroo Island[3]		
INDIA		
Ceylon[4]	River gravels	Thorite, thorianite
AFRICA[5]		
Southern Nigeria:		
Oban Hills, Kukuruku Hill		
MALAY STATES[6]		
Pahang	Placer deposits. (Monazite said to contain 8.38% thoria)	Cassiterite

[1]Rec. Geol. Survey New South Wales, Vol. VII, Pt. 3, p. 222, 1903.
[2]Rec. Geol. Survey New South Wales, Vol. VII, Pt. 4, pp. 276-283, 1904.
[3]Min. World, July 6, 1907.
[4]Cey. Adm. Rpts. 1906, Part IV, pp. E-3 and E-4.
[5]London Mining Journal, Dec. 29, 1906.
[6]New York Globe, April 27, 1907.

Monazite Areas in the United States

The workable deposits of monazite in the United States occur in the South Mountain region of North Carolina and adjoining counties of South Carolina; in the alluvial deposits along the streams from the great granite area around Centerville, Idaho; and the deposit near Mars Hill, Madison County, North Carolina.

On account of the commercial importance of these areas, their geological occurrence is described in considerable detail below:

The South Mountain (North Carolina) Monazite Region

The rocks of the monazite area of the South Mountain region, North Carolina, are for the most important gneisses, schists, and granites. These vary considerably, and are grouped under the following heads:

1. Carolina gneiss.
2. Roan gneiss.
3. Granites.
4. Pegmatites.

The Carolina gneiss is the oldest formation and is of Archean age. Its structure varies considerably, the more common types being mica, garnet, cyanite and graphite gneisses and schists. Associated with this Carolina gneiss to such an extent that it is a rather characteristic feature is pegmatite and, as will be seen later, this pegmatite is common throughout the portions of the area that carry monazite in commercial quantity.

The Roan gneiss, which is the next oldest formation in the monazite region, consists almost entirely of hornblende gneiss and schist. The granites of the area are gneissoid, porphyritic and massive in structure and, while of uncertain age, they are probably Archean.

The pegmatite occurs in two distinct phases: one in which it forms distinct masses or bodies with the typical composition and texture of pegmatite, while the other phase is a pegmatized gneiss which represents the addition of the pegmatite minerals to the gneisses, which has caused a partial recrystallization of portions of the gneiss. The structure of the pegmatite is irregular, occurring in some places in sheets or lenses interbedded and folded with the enclosing gneisses and schists, while in other places it occurs in dikes, veins or lenses either conformable with the enclosing rocks through part of its extent and cutting across them in other parts, or in irregular masses having no definite orientation with respect to the accompanying formations. All the rocks in this area are more or less weathered and decomposed and a clue to the nature of the rock formations themselves is often obtained by a study of the character of the gravels in the bottom lands and streams draining a particular region. Thus, a very light colored gravel with quartz debris indicates

a granite or a very highly pegmatized country rock. Garnet and hematite iron ore, with fragments of mica or cyanite gneiss, indicate Carolina gneiss. When quantities of black sands containing magnetite, ilmenite, hornblende, etc., are found in the stream gravels, it is an indication of the Roan gneiss. Monazite occurs for the most part in the pegmatized gneiss and schist bodies which are phases of the Carolina gneiss. The texture developed during the pegmatization is generally porphyritic and there may be a gradation from the porphyritic gneiss into more or less highly pegmatized gneiss and from this into regular pegmatite.

In those beds or portions of beds where there has been little pegmatization, there is but a small amount of monazite. It is also true that where pegmatization has been complete and but little of the original gneiss remains, there is but little monazite. The chief occurrences of the monazite are in those portions of the gneisses and schists which have been highly pegmatized and are rich in secondary quartz and contain numerous small masses of feldspar with some biotite, graphite and other accessory minerals. The monazite is nearly always well crystallized, although the crystals are extremely small. The percentage of the monazite in the rock is very small and will not average over .75 of one per cent. An attempt has been made to work the rock itself, but it was found impossible to do so at a profit on account of the low percentage of monazite.

Associated with the monazite in the sands derived from the alteration and erosion of these granites and gneisses is zircon, which is always present, and usually garnet, ilmenite, magnetite, rutile, xenotime, staurolite, syenite, and titanite (sphene).

The origin of the monazite in the pegmatized gneisses and schists was either by the bringing together of the elements necessary for its formation from the original rock during recrystallization, or by the introduction of these elements into the pegmatizing materials from external sources. This form of pegmatization is usually in close proximity to granite masses which gives evidence of its formation through magmatic agencies.

The percentage of monazite in both the original rock matrix and the gravel deposits is small, and probably does not often exceed 1 per cent. Figures are not available for the percentage of monazite in gravel deposits. From the saprolite underlying the F. K. McClurd mine, 0.75 mile northeast of Carpenter Knob, N. C., George L. English obtained about 5 ounces of monazite per ton, or about 0.016 per cent. At the British monazite mine, 3 miles northeast of Shelby, N. C., the quantity of monazite in the hard rock formations was found by Hugh Stewart, engineer in charge, to run from less than 0.03 per cent up to more than 1.1 per cent.

Madison County (North Carolina) Monazite Area

Associated with the Carolina and Roan gneisses of Madison County, North Carolina, about 4½ miles southwest of Mars Hill, there is an unusual occurrence of monazite.

The principal country rocks of this area are Carolina and Roan gneiss and Cranberry granite.

In this particular vicinity the Carolina gneiss occurs as outliers from the main formation and is not interbanded with Cranberry granite. Immediately to the east there is a large mass of Roan gneiss and this is also observed further to the west. The Cranberry granite as it occurs in this vicinity is also in the form of outliers or apophyses from the main mass lying to the north and west. It is an igneous rock composed of quartz and orthoclase and plagioclase feldspar with biotite, muscovite, and, in places, hornblende as additional minerals. There are a number of accessory minerals such as magnetite, ilmenite, garnet and epidote, found in the granite. This granite occasionally contains pegmatite areas and, on the Whiteoak Creek, a great deal of the gneiss and granite was pegmatized.

There are no extensive areas of rocks outcropping on this hillside. Occasionally small boulders of the partially decomposed granite were observed containing more or less epidote and ilmenite, forming a sort of ledge running around a hill about a third of the way to the top. About 100 feet up the hillside a shaft has been sunk to a depth of 45 feet. The rocks were decomposed throughout this distance so that no blasting whatever was necessary. On account of the excessive decomposition of the rocks, it was difficult to determine what the rocks at this particular point were. They had the appearance, however, of being decomposed Cranberry granite. The section exposed by the shaft showed the rocks to be more or less pegmatized and to carry monazite the whole depth of the shaft. The monazite seemed to occur in the pegmatized band of the rock, which, in the shaft as exposed, had a width of 2½ to 4 feet and does not occur in any sense in a vein formation.

The monazite, which is of a clove brown color, was found in fragments or rough crystals varying from pieces the size of a pea up to a large rough crystal that weighed almost exactly 60 pounds. No attempt was made at this time to determine the percentage of monazite that the rock would carry. One or two pans full of the monazite-bearing portion of the rocks were dug out, which gave nearly a pound of monazite.

As stated above, the monazite is in the form of irregular fragments, rough crystals and cleavable masses. One of the best crystals observed was a part of a mass that weighed 6½ pounds, which was made up of crystals in parallel position with some of the facies very perfectly

developed. Another crystal, which was well terminated, weighed 12 ounces.

The masses of monazite were very pure and one analysis made to determine the percentage of monazite in the masses showed it to contain 99.5 per cent monazite. No chemical analyses have been made of the mineral beyond the determination of thoria. This determination, which was made in the laboratory of the Welsbach Light Company, showed this monazite to contain 5.06 per cent thoria, which is equal to the percentage of thoria in the best commercial monazite found in the South Mountain region.

The size of the crystals of monazite found in this deposit and the possibility of its developing into an occurrence of commercial value make the discovery a most interesting one.

Monazite in Idaho

Monazite was first reported from Idaho in 1896 by Waldemar Lindgren.[1] No particular attention was paid to the occurrence of monazite in Idaho until 1905, when investigations were carried on by the United States Geological Survey at Portland, Oregon.[2] These investigations were the testing of black sands and their concentrates from various portions of Western United States to determine the metals and rare minerals they contained. Sands from many localities in Idaho have been tested and monazite was found in sand deposits on streams in the following counties: Ada, Boisé, Canyon City, Idaho, Lemhi, Lincoln, Nez Perce, Owyhee, Shoshone and Meadows.

Most of the streams in these counties from which the monazite was obtained head near or traverse a very large granite batholith that extends in length a distance of 300 miles north and south through central Idaho, and has been followed eastward through the Bitterroot Range into Montana, varying in width from 50 to 100 miles. This large granite area embraces the whole upper drainage of Boisé and Payette rivers, extending northeastward beyond the Sawtooth Mountains. The granite areas in the vicinity of Centerville and on Musselshell Creek is supposed to be part of this same great granitic batholith. Monazite has been found in some streams that are apparently without the area of this main granitic area, and it may be that this monazite is derived from granite that is occurring as offshoots or apophyses from the main granitic batholith, which have been intruded into the outlying schists.

As determined by Lindgren this granite is pre-Tertiary. It is a light gray, medium-grained rock, having in places a porphyritic texture. Some seams of muscovite mica, quartz, and feldspar have been observed

[1] 18th Annual Report, U. S. Geol. Survey, Part III, 1898, pp. 677-679, and Part III, pp. 630-632.
[2] U. S. Geol. Survey, Min. Res., 1905, pp. 1175-1258.

that had a pegmatitic character. The monazite is considered as an original constituent of this granite, and that found in the placer deposits has been deposited during the decomposition and erosion of the granite. Mr. Douglas B. Sterrett tested some of the loose sandy granitic soil which was found to carry an appreciable quantity of monazite. He also tested another sample of decomposed granite from the apex of a small hill, which yielded a few grains of monazite and zircon. This supports the idea advanced that this large granite area is the source of the monazite. The minerals associated with the monazite are magnetite, ilmenite, garnet, and zircon, which are very similar to those found associated with monazite in the Carolinas. The monazite from several localities has been tested for its thoria content, with varying results. Monazite concentrates from the Centerville region, Idaho, have been tested and gave results varying from 2.41 to 4.60 per cent thoria. This monazite represented the cleaned mineral, such as would be shipped as a commercial product. These determinations were made by R. C. Wells and W. F. Hillebrand of the United States Geological Survey. Tests reported by the assayer of the Centerville Mining and Milling Company, who own monazite lands along Grimes Creek and Quartz Creek, showed 5.2 per cent thoria for a 100 per cent pure sand or 4.94 for a 95 per cent shipping sand. The determination of the thoria content from Musselshell district varied from 0.88 to 1.85 per cent thoria of sands varying from 31.8 to 55.36 per cent monazite. If this sand had been concentrated to 90 per cent, it would give a value of approximately 3 per cent of thoria. The thoria contents of these Idaho sands are somewhat lower than from the Carolina sands.

Monazite Localities and Their Development

As was stated above, the commercial deposits of monazite are not found in the original rocks but in the gravel deposits of the present and former streams, which have resulted from the disintegration and erosion of the crystalline rocks that contain monazite. As these rocks have been altered and decomposed to a considerable depth, they are at the present time in a state of constant erosion, and their mineral constituents, as monazite, zircon, magnetite, ilmenite, garnet, etc., are being deposited in the soils and gravels. This is going on to such an extent that in the Carolinas when several years have elapsed, after the soils and gravels have once been worked for monazite, it has been found profitable to wash the accumulated soils and gravels again.

There has only been one locality where an attempt was made to work commercially the monazite in the original rock, and this is described below.

Early in the eighties when a commercial demand arose for monazite, available localities were rather limited and were confined to the Carolinas in the United States, the Bahia deposits of Brazil, and more limited deposits in Russia. Since that time the localities, where monazite is known to occur, have been multiplied, and several new localities have been discovered that contain commercial deposits of this mineral, such as those in Idaho and Montana in the United States, the Australian deposits, and those of the Malay States. Only those localities in the United States are described in any detail; others are mentioned, only as they have affected the production of this country.

The Carolina Localities

Monazite was first found in the Carolinas in the year 1879 at Brindletown, North Carolina, by Mr. W. E. Hidden. At the time that the monazite placer deposits began to be developed about 1886, localities of commercial value were known to exist in Burke, Cleveland, McDowell, Polk, and Rutherford counties, North Carolina, and in Spartanburg and Greenville counties, South Carolina. Since that time the area has been very much extended, and now localities containing deposits of monazite sands are known to occur in Alexander, Burke, Catawba, Caldwell, Cleveland, Gaston, Iredell, Lincoln, McDowell, Polk, and Rutherford counties, North Carolina; and in Anderson, Cherokee, Greenville, Laurens, Oconee, Pickens, and Spartanburg counties, South Carolina. The larger towns within or near the monazite region of North Carolina are: Statesville, Taylorsville, Hickory, Rutherfordton, and Shelby; and in South Carolina, Gaffney, Spartanburg, and Greenville. (See Plate I.)

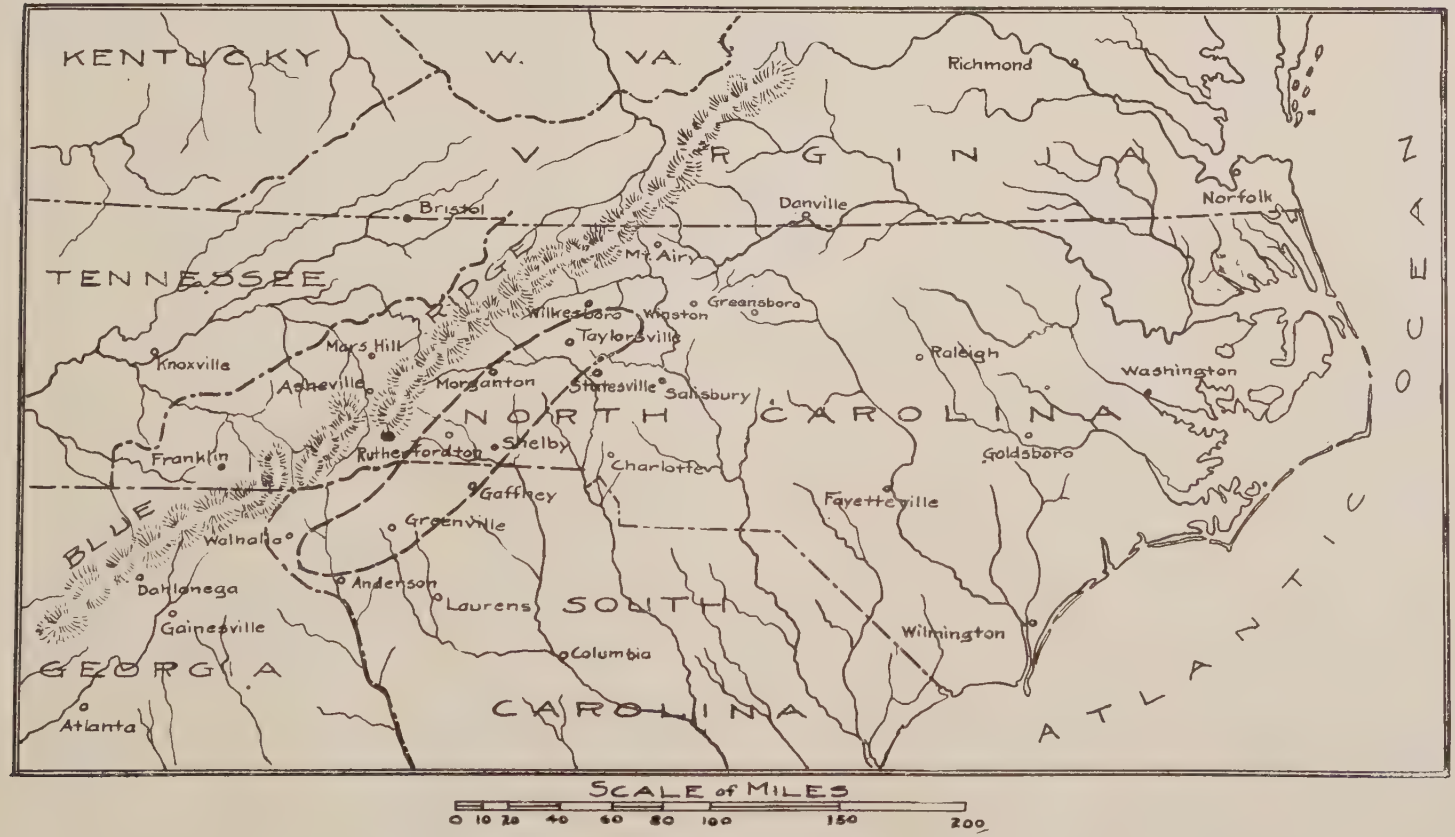
The deposits are rather favorably located for railroad transportation, as the region is traversed by the Southern, Seaboard Air Line, Carolina and Northwestern, and the Carolina, Clinchfield and Ohio railroads.

A description of the localities that were being worked, as the monazite industry approached its zenith in 1905, will give a general idea of the monazite field of the Carolinas.[1]

Rutherford County. One of the centers of the monazite mining industry in North Carolina was at Ellenboro, Rutherford County, near which place was located the property of the German-American Monazite Company, which employed about 25 men, who washed out about 1½ tons of cleaned sand each week. Their workable gravel was from 20 to 100 yards wide, and extended for a half mile up and down the creek. In obtaining this gravel they had to remove an overburden of from 1 to 5 feet in depth, some of which carried a small amount of monazite.

The Louisa Smart mine, three miles from Ellenboro, produced three

[1]Pratt, Jos. Hyde, Min. Res. of the U. S., 1903, pp. 1164-1167.



Map showing location of monazite areas in the Carolinas as indicated by dotted lines.

different colored monazite sands, which were obtained from gravels not more than 100 yards apart. The product from one portion gave a sand of decided greenish color, the second a brownish red sand, and the third a yellowish. The greenish sand was found in the gravels along the small branch, while the brownish red sand was obtained from gravels and detritus higher up on the hillside, about 60 feet from the stream. These gravels are about 3 feet thick, and covered by from 2 to 3 feet of overburden of red clay. The yellowish sand was obtained farther down the branch. There was a scarcity of water at this locality, which prevented its being more thoroughly developed. One interesting occurrence noted at this property was a pegmatitic dike, which cuts the hornblende gneiss. This dike contained many garnets, some the size of a walnut, and which was also proved by panning to contain monazite.

Rutherfordton was another center of monazite mining, some of the principal work being on the land of Mr. A. D. K. Wallace, two miles from Rutherfordton. Gravels worked were in the bottomland and were 100 feet across and from 1 to 3 feet thick. The overburden was slight, contained some monazite, and was washed with the gravels.

There were workable gravel deposits, varying from 50 to 100 feet in width on this property, which extended along the creeks for a quarter of a mile. Half a mile west of the Wallace deposits on the land of Mr. H. Harris, gravels occurred up and down the stream for a distance of nearly a mile, and were worked for their monazite content. At Peppertown Creek in the same neighborhood, a small amount of work was done, but on account of the very large percentage of black magnetic sand the concentrates were low in monazite, and thus the amount of work done was limited.

At Duncan, 17 miles from Ellenboro, there were 38 acres of bottomland extending along about a mile of the stream, which were worked by Mr. Henry Gettys. Both the gravel and overburden were washed.

Cleveland County. Shelby, Cleveland County, is the center of the monazite industry for a considerable territory, and the magnetic concentrating plant of the Welsbach Light Company of Gloucester, New Jersey.

Six miles from Casar, Cleveland County, on the land of Mr. A. M. Hunt, there were good workable deposits of gravel that varied in thickness from 2 to 3 feet, and also a good width of bottomland. There was an abundant water supply, so that all this material was run through sluice boxes. Near the upper end of this land was one of the localities where the alluvial material could be worked over profitably several times on account of the rain constantly bringing down new monazite from the adjoining lands.

In the vicinity of Carpenters Knob on the headwaters of Little Knob

Creek, several good monazite gravel deposits were worked by the Incandescent Light & Chemical Company of New York. The bottomland gravels that were worked varied from 30 to 70 yards in width, and averaged about 2 feet in thickness.

Further down the creek on what was known as the McSneed property, the gravels were observed in one place to be 7 feet thick. This company also owned and worked monazite gravels, known as the Lattimer mine, near Shelby.

Near Mooresboro there was a considerable area of bottomlands, and the gravels have been worked for a distance of about a mile, the deposit being about 100 yards in width. The sand obtained from these deposits carry a large percentage of magnetite.

Burke County. In Burke County considerable sluicing for monazite was carried on at the gravel deposits on Brindletown Creek and its tributaries. Some of the most noted properties were those of J. E. Mills, John Kirksey, and Moore Epley.

The Incandescent Light and Chemical Company of New York worked monazite gravels on Camp Creek.

McDowell County. In McDowell County, monazite gravel deposits are to be found in the waters of Silver, South Muddy and North Muddy creeks, and Henry and Jacobs forks of the Catawba River. The thickness of these stream deposits is from 1 to 2 feet, and the percentage of monazite varies from an infinitesimal quantity up to 1 or 2 per cent. On account, however, of an act of the Legislature, which prohibits the use of these streams for sluicing purposes, there has not been any mining for monazite in these regions for many years.

In South Carolina the principal localities where monazite was produced were in the vicinity of Cowpens, Spartanburg County; Gaffney, Cherokee County; and Greenville, Greenville County.

Production of Monazite in North Carolina

A large part of the monazite produced in the Carolinas was obtained in small amounts principally by farmers.

The Carolina monazite industry may be said to have begun in 1886. The first shipment of monazite was in 1887, when twelve tons of monazite sand were shipped from Brindletown District of Burke County, North Carolina. A certain tonnage was shipped from the Carolina deposits annually until 1911, when for causes described later, the production of monazite came to a standstill in the Carolinas. There has been a very great variation in the amount of shipments each year, which, however, has been due principally to trade conditions, and not to any decrease in the supply. The monazite industry reached its maximum in 1895, when there was a production of 1,573,000 pounds valued

at $137,150. It was in this year that the Brazilian monazite entered the market in direct competition with the American monazite, and it unsettled the market so quickly that during the next years, 1896 and 1897, the monazite industry in the United States was about paralyzed, the production amounting to only 30,000 and 44,000 pounds per year respectively. It was also in the year 1895 that Norway began to ship thorite in considerably greater quantity.

In 1897 the industry began to recover, and the production of monazite continued to increase until a new record was established in 1905, when the production was 1,352,418 pounds valued at $163,908. The next year, however, it was approximately the same; but in 1907 the production began to decline very rapidly, and in 1911 there was no production of monazite from the Carolina deposits. This second decline was also partly due to the production from the Brazilian deposits. In the table below there is given the production of monazite in the Carolinas from 1893 to 1911:

PRODUCTION OF MONAZITE IN THE UNITED STATES, 1893–1911.

Year	Quantity, Pounds	Value	North Carolina	
			Quantity, Pounds	Value
1893	130,000	$ 7,600	130,000	$ 7,600
1894	546,855	36,193	546,855	36,193
1895	1,573,000	137,150	1,573,000	137,150
1896	30,000	1,500	30,000	1,500
1897	44,000	1,980	44,000	1,980
1898	250,776	13,542	250,776	13,542
1899	350,000	20,000	350,000	20,000
1900	908,000	48,805	908,000	48,805
1901	748,736	59,262	748,736	59,262
1902	802,000	64,160	802,000	64,160
1903	862,000	64,630	773,000	58,694
1904	744,999	84,838	685,999	79,438
1905	1,344,418	162,308	894,368	107,324
1906	846,175	152,312	697,275	125,510
1907	547,948	65,754	456,863	34,824
1908	422,646	50,718	310,196	37,224
1909	541,931	65,032	391,068	46,928
1910	99,301	12,006	83,454	10,104
1911–1915	0	0	0	0

Up to 1901 the production of monazite in the Carolina fields was largely by farmers with smaller amounts by American companies that bought tracts of land in the monazite region. During 1901 a number of representatives of German manufacturers began to investigate the Carolina monazite region, and during 1902 purchased a considerable acreage near Ellenboro, Cleveland County. Soon after they became amongst the larger producers of monazite sand, which they refined in their magnetic cleaning plants. All their product was shipped to Germany.

In 1903 there were three companies—the German-American Monazite Company, the Incandescent Light and Chemical Company, and the Welsbach Light Company, which had erected magnetic concentrating plants in the Carolinas, and were either mining or buying monazite sands. These companies continued in operation practically up to the time the monazite industry ceased in 1911.

Mining and Cleaning Monazite Sands

The Carolina District[1]

In addition to the ordinary placer deposits containing monazite sands, it has been found in some cases profitable to sluice down and concentrate the surface soils on the lands adjoining some of the richer monazite-bearing deposits. The residual soils that have suffered but little displacement on the surface can thus profitably be washed to a depth of 3 or 4 inches, and where the drift-soil has collected on the gentle slopes below a steeper hillside, it has been found profitable to sluice down in some cases. The partial concentration of monazite in the top layer of soil is caused by the washing away of the clay and other light decomposition products of the rock. The supply of monazite in the stream gravels in favorable areas is often replenished by the wash from the hillside soils during rains, especially where the hills have any considerable slope and the land is cultivated. Under such conditions the stream-gravels are often worked two or more times in a year.

The saprolite or rotted rock underlying the richer deposits of monazite was at some places sluiced down to depths of from a few inches to a foot or so, along with the overlying gravels. At other places, small amounts were removed and washed separately for the monazite they contain. The formations that have been found especially favorable for such work are highly pegmatized gneiss or schist. Such deposits have generally soon been lost or grown poor, probably due to the fact that the miners had cut through the richer beds or failed to follow it in the direction of its extension. The occurrence of monazite in saprolite is merely an altered phase of the occurrence in hard rock formations.

With the exception of the plant of the British-American Monazite Company, mentioned below, all the monazite mined in the Carolinas has been obtained from gravel deposits which lie in and along the stream and creek beds, where the monazite is collected after having been liberated from the rocks by their alteration and erosion. While no accurate record has been kept of the percentage of monazite in these gravel deposits, yet it is undoubtedly true that the quantity present, reckoning from surface to bed-rock, does not exceed one per cent. This amount,

[1]Nitze, N. C. Geol. Survey, Bull. 9, pp. 31-35, 1895; Pratt and Sterrett, Transaction Am. I. M. Eng., Vol. XL, 1910, pp. 313-340.

however, is sufficient to make profitable mining. In many localities it has been the custom to sluice not only the gravels but all the overburden, inasmuch as even the topsoil carries a small amount of monazite.

The separation of the monazite from these gravels consists of two distinct processes: (1) a wet concentration in which the sands are partially concentrated by means of sluice boxes and concentrating tables; and (2) one in which the material has to be perfectly dry and the monazite is separated by means of magnetic separators.

There have never been any large hydraulic plants in operation, but nearly all the monazite is obtained in sluice boxes fed by hand. These boxes are fitted at their upper end with a sieve or shaking-hopper, with mesh of about No. 12. The boxes vary in length from 5 to 20 feet, and in some instances are fitted with riffles holding mercury for catching any gold that might be present.

Hydraulicking has been introduced in a few localities where the gravels contained a greater quantity of gold, but for the most part the monazite has been treated in sluice boxes. In 1906-7 Wilfley concentrating tables, or ones of similar type, were introduced in a few places for treating the concentrates from sluice boxes. The concentrating table was set up at the mine as conveniently as possible to the gravel deposit that was to be first concentrated by the wet method, and was usually operated by gasoline or kerosene motor. Where these tables were used the soil and gravels were washed into shaking-hoppers and then through sluice boxes, the over-size thrown out, and the sands fed to the Wilfley tables. At one mine it was necessary to raise the gravels by a mechanical elevator in order to bring them to a sufficient height to feed them to the table. They were fed into a revolving screen and from that to the table. The heads from this first washing did not contain a very large content of the monazite, and the middlings were, therefore, refed to the table with other feed-ore. In some cases the feed-ore was all run over the machine and a rough concentrate first obtained and then this refed. The product from these machines contained from 30 to 70 and occasionally 80 per cent of monazite. Where there was a large amount of the heavy black sands occurring in the gravel with the monazite, it was almost impossible to get the concentrate much higher than 30 per cent of monazite. Where, however, these sands occur more sparingly, it was possible, by this method, to obtain a concentrate containing 70 per cent of monazite.

All the concentrates from the sluice boxes and Wilfley tables have to be dried before they can be treated on the magnetic separators. Two different methods were in use in the monazite district for this purpose. In one the sand is spread over an oiled or a rubber cloth in a thin layer and exposed to the heat of the sun. It dries very quickly, due, perhaps,

partly to the heat absorbed by the dark, iron sand. It requires, however, a considerable surface to accommodate any large amount of sand. The other method of drying is by heating over furnaces. A small ditch, from 4 to 8 feet long and from 1.5 to 2 feet wide and about one foot deep, is dug, at one end of which there is built a rock or brick chimney. The ditch is usually built up of stones, with an opening at the end opposite the chimney for firing. Over the ditch there is a sheet-iron cover or drying plate. The monazite is spread on this plate and exposed to the action of the hot fire underneath. The dried sands are occasionally further concentrated by means of the ordinary horseshoe magnet, which picks out all the magnetite.

This product was sold by the miners to companies that were operating magnetic concentrating plants, and the miners were paid for the sand on the basis of the product containing 100 per cent monazite, and therefore the higher the concentration the better the price they received. The sand brought in to the magnetic concentration plants varied in value from 4 to 8 cents per pound. When it had been treated in these plants its values increased from 12 to 20 cents per pound. This material represents what is known as crude monazite, and contained besides the monazite, magnetite, ilmenite, garnet, zircon, rutile, corundum, cyanite, hornblende, and occasionally chromite.

The degree to which the monazite sands can be cleaned on the concentrating tables by the wet method is dependent largely upon the mineralogical composition of the gravels. Those that are in the vicinity of hornblende rocks, which means that the sands will contain considerable magnetite, ilmenite, and other iron minerals with high specific gravities, the concentration will seldom run over 5 per cent of monazite, and it sometimes is as low as 15 or 20 per cent. This is the case in the Golden Valley and Brindletown regions. On the other hand, when the gravels are in the vicinity of the micaceous rocks, a much higher concentration can be obtained, this running in some places as high as 75 per cent, although the general average is from 40 to 50 per cent. Such deposits are those at Carpenters' Knob, at the mines near Ellenboro, and other places.

Magnetic Separation. The first application of magnetic separation was in the concentration of certain iron ores, principally magnetite, in order to produce a product richer in iron and also to eliminate certain minerals that contained elements injurious to the metallic iron. The next application was to other iron ores such as limonite, hematite, and siderite, after they had been given a preliminary roasting to convert them into the magnetic oxide. The next step was in the separation of magnetic iron particles from certain copper, gold and zinc ores either

before or after roasting. For many years this was the only application made of magnetic separation. It was found, however, upon experimenting with an electro-magnet with a higher intensity that other minerals were subject to magnetic attraction and that it was possible to separate minerals into more or less pure products by varying the intensity of the magnetic field. Thus, it has been possible to adapt this method of separation to ores containing iron or manganese which are only weakly magnetic. As is well known, steel bars may be magnetized and they will retain more or less of this magnetism indefinitely, while bars of softer wrought or cast iron may be magnetized by means of electric currents in surrounding coils of insulated copper wire. These iron bars do not become permanent magnets, but form electro-magnets as long as the current flows around them. They can be given a greater and more constant strength than can be given to the permanent steel magnets and for this reason, in nearly all of the magnetic processes, electro-magnets are used instead of the field magnets.

The magnetism of these electro-magnets can be varied and different intensities obtained ranging from indefinitely weak to a certain maximum of strength. It is also possible to control the intensity of any magnetic field so that minerals that are strongly attracted may be separated from minerals that require a magnetic field of much higher intensity. This intensity of the magnetic field depends:

1. On the size of the magnet.
2. On the shape of the magnet.
3. On the distance between the magnet and the body to be attracted.
4. On the number of ampere turns in the magnet coil; that is, the product of the amperes or current flowing in the coil times the number of turns around the core.

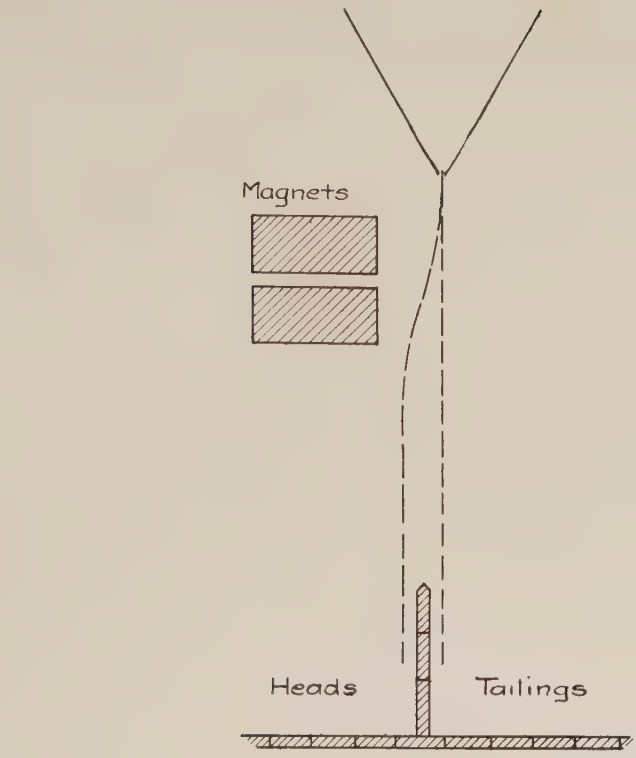
There are many substances that are attracted by electro-magnets which are not influenced apparently at all by the strongest steel magnet and for this reason, formerly many substances which were considered non-magnetic, have been proved to be magnetic when subjected to the intense magnetic field obtained in an electro-magnetic separator. All substances are, of course, either attracted or repelled by magnets and the former are called para-magnetic and the latter dia-magnetic. The latter class is the most numerous, but since the introduction of electro-magnets, the former class, which, up to this time, had been considered extremely small, has been largely increased. The para-magnetic substances are the metals iron, nickel, cobalt, manganese, chromium, cerium, titanium, palladium, platinum, osmium and many of their salts and compounds. The degree of attraction of these varies very widely and, as an illustration between a strong and weak magnetic

substance, it has been estimated that if the attraction of steel be taken at 100,000, then magnetite would be 65,000, siderite 120, hematite 93 to 43, limonite 72 to 43. By using the electro-magnetic separators, which can be regulated so as to give a very strong field and at the same time a field which is capable of fine adjustment, it is now possible not only to separate the para-magnetic from the dia-magnetic substances, but also to separate the para-magnetic from each other.

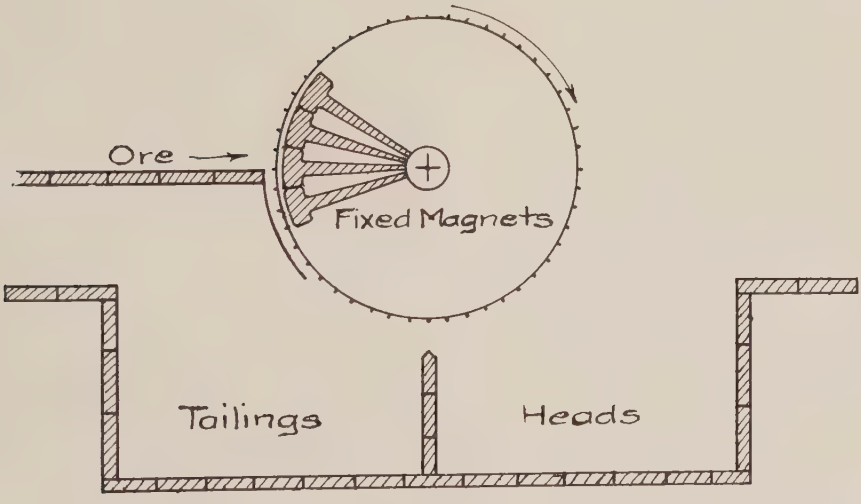
There are a large number of magnetic separators that have been invented, many of which are now on the market. Perhaps the simplest of all these magnetic separators is one devised by Edison. In this separator the particles of mineral are permitted to fall in a thin sheet in front of the poles of a strong bar electro-magnet, which causes a deflection of the magnetic particles from a direct downward path, while the non-magnetic particles would not be influenced by this attraction and would fall vertically. It is possible to make two and sometimes three products in this way. (See Plate II, A.)

There are four general classes of these magnetic separators as follows: (1) in which the magnetic particles are held to revolving cylindrical rolls or drums within which are magnets; (2) those in which the magnetic particles are carried by conveying belts or pans passing over the magnets; (3) those in which the ore falls in front of a magnet; and (4) static machines. There are a number of points of difference in the machines such as permanent or electro-magnets; treating the ore wet or dry; magnets acting continuously or intermittently; and the use of a direct or alternating current. It will be found that different machines are suited for different purposes according to the character of the material to be treated. As I have stated before, most of the machines were originally designed simply to treat iron ores, or to separate iron minerals from other ores and there are but few of them that are adapted for the separation of monazite, zinc minerals, etc.

1. A separator representing the first class is the Ball-Norton separator which consists of two revolving drums within each of which is a series of stationary electro-magnets so wound that opposite poles are adjacent to one another. The capacity of a machine with 2 drums 2′ diameter and 2′ face varies from 15 to 20 tons per hour, 16 to 20 mesh. The ore is fed upon the top of the first drum and the magnetic particles are held by the drum, while the non-magnetic fall into the hopper below. As the drum revolves, the magnetic particles get beyond the magnetic field and are thrown by centrifugal force on to the second drum. This drum, which does not have quite so strong a current as the first, does not attract as many of the magnetic particles so that some of these drop off into a second hopper, forming a middling product, while the stronger



A



B

A. Section of Edison type of magnetic separator.
B. Section of the Heberli dry magnetic separator.

magnetic particles are held by the drum and carried a certain distance, when they get beyond the magnetic field and are dropped into a third hopper. On account of the alternate polarity of the adjacent magnets, the particles roll over and thus facilitate the elimination of any gangue particles that may be mixed with the magnetic.

Another simple drum separator is the Heberli, in which there is but one drum and the electro-magnets extend over about one-fourth of the area of the drum. The ore is fed to the drum just above the center radius and about the middle of the magnets. The drum revolves in the opposite direction to which the ore is fed and the magnetic particles are attracted by the drum and carried up and over the magnets while the non-magnetic particles drop into the hopper below. As the magnetic particles leave the magnetic field, they are dropped on the opposite side of the drum in another hopper. (See Plate II, B.)

2. It is the magnetic separators of the second class that have been used principally in the separation of monazite in the Carolinas. Of these machines, the Wetherill stands out most prominently and was probably the first to commercially treat weakly magnetic materials. The principal idea of these machines is to secure a very strongly magnetic field by concentrating the lines of force as far as possible, this being accomplished by placing the two poles of the magnet facing one another with a minimum gap between them and by bevelling down the pole pieces to their end. (See Plate III, A and B.)

This electro-magnetic machine was the first to be used in concentrating monazite sands, and this machine and its modifications has been used to a greater extent than any of the others. The type of Wetherill magnetic separator that is more generally used is known as the Rowand[1] type, which has a magnetic pole with sharp edge above the traveling feed-belt and a blunt pole directly under it. Both of these poles are capable of being magnetized by an electric current which will produce a condition varying from weak to intensely strong magnetism. The concentration of magnetism at the sharp edge causes all the magnetic grains to jump to the upper pole. A cross-belt directly beneath this pole, which is running rapidly at right angles to the feed-belt, readily takes off these grains and deposits them in a bin, while the non-magnetic grains go on with the feed-belt. There can be readily arranged above the traveling feed-belt a series of such poles, each stronger than the one before, so that the first will take off the strongest magnetic particles. The feed-belts used vary in width from 12 to 18 inches. The material fed to the machine is classified and allowed to pour over a revolving drum, which concentrates it evenly over the feed-belt. The pole-pieces

[1]Ore Dressing, by R. H. Richards, Vol. II, p. 807, 1906.

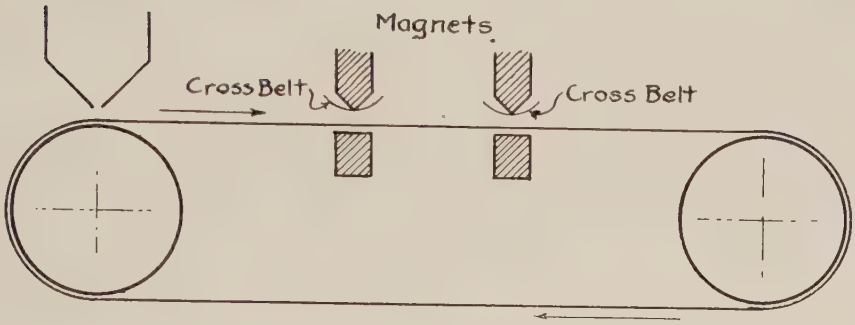
are made of soft iron, and weigh up to 90 pounds each. They are adjustable, so that the length of air-gap between them may be varied. The strength of the current in amperes can be varied, and also the distance of the feed-belt beneath the poles.

The monazite sand, which is fed to the traveling feed-belt, passes along under four powerful electro-magnets. The first removes all the magnetic iron, and generally all of the titanic iron, or ilmenite, and any chromite that might be present. The second magnet removes all the fine grains of garnet, the coarser ones, if present, usually being removed by the first magnet. The third magnet is so adjusted as to remove only the coarser particles of monazite, while the fourth removes all the finer pieces of monazite. The remaining portion of the sand, consisting largely of zircon, quartz, and a little rutile, corundum, cyanite, etc., is dropped off at the end of the large belt into the waste pile.

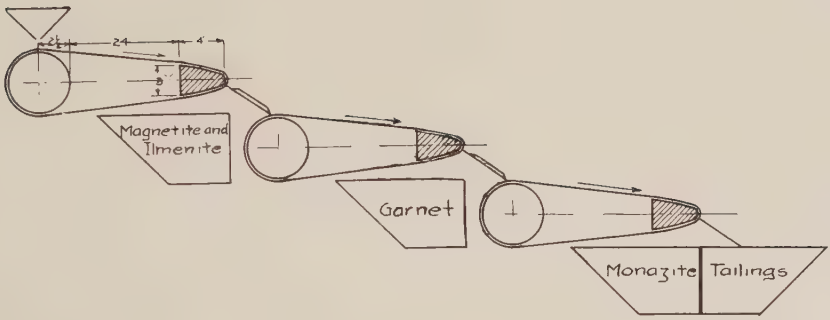
A modification of this machine which has been worked out and been in use in the Carolina field, consists of a series of magnets, over which are traveling belts, which pick up different minerals, according to the intensity of the magnetic field. In this machine the magnetic particles are carried over and under the magnet and dropped into a hopper as they leave the magnetic field, while the tailings are dropped into another hopper and fed to another traveling belt and over a second magnet of stronger intensity, which picks out the garnet. This is dropped into a special bin and the balance into another hopper and fed to a third magnet, which picks out the monazite. It is possible by these separators to obtain a monazite sand of from 90 to 99 per cent of monazite, according to the care that is taken in separating it.

The other products, as the iron minerals, magnetite and ilmenite, and garnet, can also be obtained in a very pure state. From a long series of experiments it has been determined that the magnetite can be removed in machines of this type when the amperage is 0.2 ilmenite with 1.1 chromite and 1.6 garnet with 1.75 hypersthene and olivene with 2.2, and monazite with 3.50, and hornblende with 5 amperes. Zircon is left behind with the gold as non-magnetic. Any platinum that might be present would begin to be lifted by the weakest current, but most of it would not be lifted until the current was 1.5 amperes.

3. In the third class of magnetic machines, the particles of minerals are permitted to fall in a thin sheet in front of the poles of a strong electro-magnet, which causes a deflection of the magnetic particles from a direct downward fall, while the non-magnetic particles are not influenced by this attraction and fall vertically. It is possible to make two and sometimes three products in this way. The minerals are usually passed over a series of belts, and the deflection is effected as the particles fall over the ends of the belts.



A



B

A. Section of the Wetherill magnetic separator, Rowand type.
B. Section of the Wetherill magnetic separator, the type that has been adopted in many of the Carolina monazite mills.

4. In using the static machine, all the minerals but monazite and garnet are taken out of the sand by means of a cylinder covered with sheets of vulcanite, which is electrified by rubbing with felt-covered cylinders, revolving at a high rate of speed. The sand is heated by gasoline lamps before being exposed to the electrified cylinders. The cylinder is revolved slowly and the sand which is attracted to it is removed by brushes. This machine has not been used to any large extent in the Carolina monazite field.

In the Idaho monazite field, several different electro-magnetic machines were used which are mentioned under Idaho.

MINING OF MONAZITE IN ORIGINAL MATRIX[1]

There has been only one attempt to mine monazite in the original rock. This was by the British Monazite Company, which represented the South Metropolitan Gas Light Company of London. In 1906 this company purchased a property known as the old Campbell mine, about three miles northeast of Shelby, Cleveland County. The plan of the company was to develop a permanent source of monazite.

The country rock is a pegmatized graphitic biotite gneiss (Carolina gneiss), which contains certain beds that have been more highly pegmatized than others. Certain of these strata carry a higher percentage of monazite, and they are distinguished from the leaner portions by their typical augen structure, due to porphyritic feldspar crystals and small bodies of pegmatite scattered through the gneiss.

When the property was worked, a quarry was opened about 150 yards long, and from 8 to 25 yards wide, varying in depth from 5 to 20 feet. In mining the rock, it was generally removed throughout the full height of the working face, and the monazite-bearing material was cobbed out. This was not difficult on account of the decided difference in appearance of the rich rocks and the lean. The ore was then hauled in tram cars, drawn by mules or horses to the mill at the southeast corner of the cut. As stated by Mr. Hugh Stewart, manager of the company, all the rock taken from the cut showed monazite, and all rock carrying 0.4 per cent or over of monazite was treated as ore, while the balance of the rock was discarded. According to Mr. Stewart, the method of treating the ore at the mill was as follows:

From the quarry the ore trammed to the mill and dumped on the feed floor, whence it receives the following treatment:

(1) Crushed in Gates gyratory crushers to 1 inch.

(2) Elevated to bin, whence it is discharged to rolls crushing to one-sixth inch diameter.

[1] U. S. Geol. Survey, Min. Res., 1906, pp. 1202–1204.

(3) Product from the latter is discharged into sizing apparatus (sieves). Material of one-fourth inch diameter or under goes through sieve and is discharged into second elevator. Material over one-fourth inch goes over sieve and is discharged into second crushing rolls, where it is reduced to one-eighth inch and is also discharged to second elevator.

(4) Second elevator sends ore into Huntington Mills, fitted with 16-mesh screens, through which the ore is discharged.

(5) Ore from the Huntington Mills is collected in hoppers and fed to 1 Wilfley and 3 Overstrom tables. The seconds and thirds from the first Wilfley and middlings from the Overstroms are passed over a second Wilfley table for final concentration.

The company found the rock to contain too low a percentage of monazite to make its separation a profitable proposition. It had no difficulty whatever in obtaining a very clean product. It dismantled the mill and disposed of the machinery in 1907.

Idaho Localities

Although monazite had been identified from Idaho as early as 1896 no special attention was paid to it until the investigations started by the United States Geological Survey at Portland, Oregon, in connection with the investigation as to the commercial minerals occurring in the black sands obtained from placer mining along the Pacific slope. As has already been stated, a large area was located in Idaho which carries a certain amount of monazite in the gravels along the streams. The first thorough test as to the commercial value of the monazite sands of Idaho was undertaken by the Centerville Mining and Milling Company, which installed machinery in 1896 for handling the concentrates from old placer workings along Grimes Creek and Quartz Creek and their tributaries in the Centerville region. The company owned about 6,000 acres along these creeks, which contained large areas of gravel beds that had been previously worked for gold. During the washing of these gravels for gold, there was a partial concentration of the monazite, but all this material was left on the dumps. The company has treated a sufficient quantity of these gravels to enable it to work out a method for extracting the monazite. It also worked a small amount of the overburden gravels, which vary in thickness in different parts of the property, in order to obtain a revenue with which to help defray the expenses of construction work on the mill. The tailings from this work were also allowed to accumulate and represent part of the material that will be treated in the mill. Two or three tons of monazite were obtained by this company during the year 1906. The results obtained were sufficiently satisfactory to induce the company to enlarge its plant in 1907 and again in 1909. This company has devised special methods

of treating the gravels for their monazite and gold contents. The gravels are run through sluice boxes, the gold caught in riffles, with quicksilver, and the tailings sent to the mill in a flume. As described by Mr. Douglas B. Sterrett,[1] who visited the mill in 1910, when it was in full operation, the method is something as follows:

The tailings are discharged from the bottom of the flume through a grizzly 12 feet long and 4 feet wide, with wedge-shaped bars one-eighth inch apart, into a chute leading to a sump in the lowest part of the mill. From the sump the sand is carried by bucket conveyor to 3 revolving sizing screens of 3, 4 and 6 mesh. The material under 6 mesh from the last screen is carried by bucket conveyor 50 feet higher to storage bins in the upper part of the mill. From the bins the wet sand is automatically fed into vats with pipes leading to concentrating tables. At the time of visit concentration was accomplished by a battery of 2 Wilfley tables and 4 Card tables. The capacity of the plant is now being increased to 12 tables, to be arranged as follows: A battery of 6 Wilfley tables below and a battery of 2 Wilfley tables and 4 Card tables directly above. Under present conditions the sand comes from the tables as first, second, and sometimes third grades with tailings. The first grade generally runs over 40 per cent monazite, the second grade contains about 25 per cent, and the third grade 10 to 15 per cent. The second and third grades are run over a Pinder table, either separately or together, and raised to a higher grade. With the new arrangements of 12 tables the second and third grades from the 4 Card tables will be run over a Wilfley table below, and the second grade from all the Wilfleys over the Pinder table.

The cleaned sand from the concentrating tables is dried in a revolving inclined cylinder by a wood fire. The dried sand is fed by a chute to a bucket conveyor and carried to a bin above the magnetic concentrators. The sand is sized, and all below 20 mesh is fed to a Lovett magnetic separator, which removes the magnetic iron. The titanic iron and garnet are removed next by one of the new types of electro-magnetic cleaning machines designed by Herman W. Freese for the company. The monazite is next removed in 5 machines of the same type with the latest improvements applied.

For the operation of the hydraulics and placers, Mr. S. K. Atkinson, Engineer and Manager of the Company, states, it was necessary to repair about 60 miles of ditches and construct one new ditch 9 miles long. This ditch has a tunnel 350 feet long under one hill and numerous bridges over small valleys. The volume of water available for mining is estimated at 5,000 miners' inches in the wet season and about half the quantity in the dry season. Water is used under varying pressure up to a head of 200 or 300 feet, and greater pressure can be obtained. The quantity of gravel that can be treated for gold and monazite is limited by the capacity of the mill. It is estimated that over 1,000 tons of tailings can be run through the mill and the monazite removed in twenty-four hours. In two tests, made on a 100-pound sample and a cubic-foot sample weighing 105 pounds, it was found that approximately one-third of the gravel is over 6 mesh and would therefore not be sent over the concentrating tables. That is 1,500 tons of gravel can be mined and treated for gold and monazite per twenty-

[1]Min. Res. U. S. Geol. Survey, *Monazite and Zircon* in 1909, pp. 898-901.

four hours. With 1 cubic foot of gravel weighing 105 pounds the capacity of the plant, 1,500 tons, is approximately 1,058 cubic yards of gravel washed through the flume per twenty-four hours.

With the exception of the Lovett machine the electro-magnetic cleaning machinery in use by the Centerville Mining and Milling Company was devised and is being patented by Herman W. Freese, of the allied company, the Black Sand and Gold Recovery Company, of Chicago. Cleaning is accomplished by means of electro-magnets arranged around the circumference of a cylinder revolving over a conveying belt. The magnets are excited by an electric current when near the conveying belt, and the current is automatically cut off when they are in the proper position to discharge the sand attracted to them. The capacity of the 5 machines removing monazite is from 2,000 to 2,500 pounds of cleaned sand per day of ten hours. The Lovett machine for removing magnetic iron and the Freese machine used to remove titanic iron and garnet have a capacity sufficient to feed these 5 cleaners. Power for operating the mill is obtained from a high potential electric power line with a generating plant on the Payette River some 12 miles distant.

Although careful records have not been kept of the per cent of monazite recovered from the gravels washed, Mr. Atkinson estimates that practically all the tailings and gravels will yield at least 0.1 per cent; the tailings from some of the old workings are known to be very much richer.

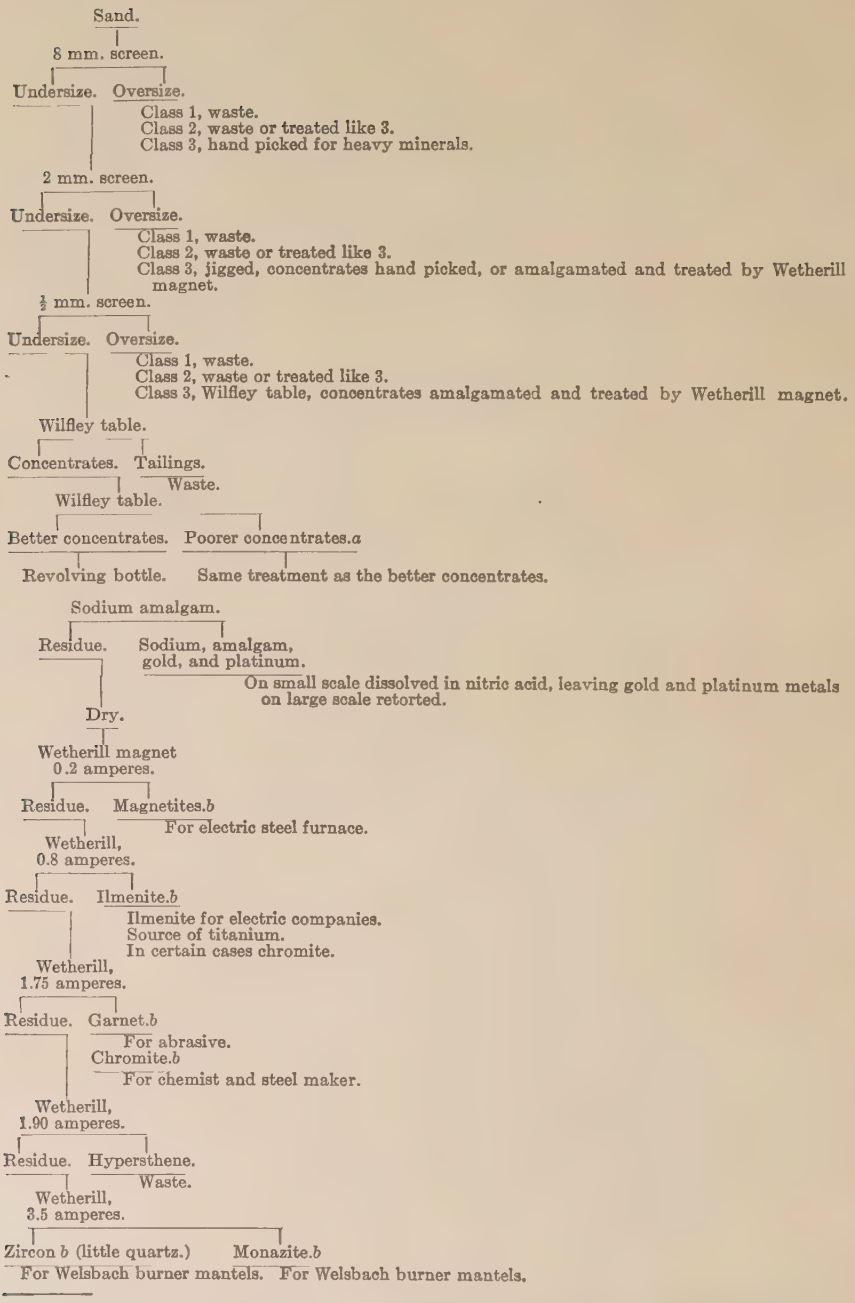
On account of the price of monazite, there has been no monazite shipped from Idaho, and the lack of market for the mineral has, of course, prevented any further development work in the Centerville region or the other portions of Idaho where monazite is known to occur. With any change in the trade conditions, which calls for American monazite, there will be a renewed activity in the Idaho field, unless the price offered for the American monazite is too low. The Carolina monazite can be produced and sold at a lower price per pound than the Idaho product.

The discovery of the occurrences of monazite in the Western States was due largely to the work of the United States Geological Survey in connection with their tests in determining useful minerals that occur in the black sands of the Pacific slope. An act of Congress, approved March 3, 1905, directed the United States Geological Survey to include in its report on Mineral Resources of the United States investigations relating to the useful minerals contained in the black sands of the Pacific slope. A subsequent act enlarged the scope of the work to embrace the whole of the United States. A very complete plant for carrying on these investigations was erected at Portland, Oregon, in connection with the Lewis & Clark Exposition, 1905. This plant was under the direct supervision of Dr. David T. Day of the United States Geological Survey. Nearly a thousand samples were tested, and these showed that the following minerals in the order given are most com-

monly found in these sands: magnetite, gold, ilmenite, garnet, zircon, hematite, chromite, platinum, iridosmium, mercury, amalgam, olivine, iron silicates, pyrite, *monazite,* copper, cinnabar, cassiterite, and corundum. The method suggested for saving the precious metals and minerals of commercial value associated in these sands as the result of experimental work is as follows:

The tree of the process recommended for commercial work on the three classes of sands in large lots is as follows:[1]

[1]Min. Res. U. S., 1905, Black Sands on the Pacific Slope, by David T. Day and R. H. Richards, p. 1238.



*a*Should the gold be encased in some other mineral and therefore can not be amalgamated, these two products should be ground finer to free the gold, and the amalgamation repeated.

*b*Each of these six minerals may need a little cleaning on the Wilfley table before being shipped.

Brazilian Monazite Deposits

The Brazilian deposits have had such an influence on the production of monazite in the United States, it will be of interest to give a brief note regarding the exploitation of this monazite.

The exploitation[1] of the Brazilian beach deposits was first undertaken by John Gordon, an American. In the early days of mining Gordon shipped monazite sand as ballast at a cost of less than $15 per ton to Hamburg, Germany, where he realized large profits on it, since the lowest price at that time for sand carrying 5 per cent of thoria was $95 to $120 per ton. Later he was forced to enter an agreement with the German combination of thorium manufacturers without being able to establish the intended monopoly of the export of Brazilian monazite. In 1903 the Brazilian legislative assembly decided that the deposits of monazite sand along the coast belonged to the Federal Government and forbade their exploitation. Later bids were let for the privilege of working these sands, and the rights were finally secured by A. C. de Freytas Company, of Hamburg. This company guaranteed a royalty of 50 per cent of the sales made and an annual production of 1,700 tons. The de Freytas Company soon went into partnership with Gordon, and together they made an agreement to sell their whole product to the German thorium syndicate. From the latter they were to receive, in addition to the selling price, a share of the profits from the sale of thorium nitrate. In this way the thorium syndicate has held a partial monopoly over the production of monazite from Brazil.

When it was found that other manufacturers of thorium products were able to obtain supplies elsewhere and that the whole output of Brazil could not be controlled, the German thorium syndicate decided to kill out all competition. Accordingly, in January, 1906, the price of thorium nitrate was reduced to nearly half of that prevailing at the time. The quantity of nitrate sold to each consumer was limited to his demands and was so placed as to conflict with the attempted sales of companies not in the thorium syndicate. In this way the acquisition by brokers of large quantities of low-priced thorium nitrate for speculative purposes was avoided. This cut in the price of nitrate has been injurious or fatal to several smaller manufacturers of thorium products who had supplies of high-priced material in stock, though it has not seriously affected larger, well established firms mining their own monazite.

The monazite exported from Brazil[2] from 1902 to 1906 was as follows:

[1]Min. Res., U. S., 1906, pp. 1205-1206.
[2]Min. Res. of U. S., 1907, p. 791.

EXPORTS FROM BRAZIL, 1902–1906, IN METRIC TONS

	Metric Tons
1902	1,205
1903	3,299
1904	4,860
1905	4,437
1906	4,351

The average price in 1904 was 11.6 cents per pound, and in 1905, 8.57 cents per pound.

Importation of Monazite and Thoria

In order to understand thoroughly and appreciate the decline in the monazite industry in the United States, it is necessary to be familiar with the imports of both crude monazite and thorium nitrate. Considering the policy of the producers of Brazilian monazite and manufacturers of thorium nitrate, as has been outlined above, which was to reduce the selling price of thorium nitrate so as to drive other producers out of the market, had the effect of causing a large amount of thorium nitrate to be imported into the United States. This importation began about 1904, and since that time the following amounts have been imported into this country:

IMPORTS OF THORIUM NITRATE INTO THE UNITED STATES, 1904–1911, IN POUNDS.

Year	Quantity	Value
1904	58,655	$ 249,904
1905	52,378	269,504
1906	40,090	139,929
1907	51,441	152,666
1908	65,289	173,239
1909	124,833	236,057
1910	124,808	219,615
1911	121,111	238,841

Prior to 1909 there was comparatively little monazite imported into the United States, and the domestic production supplied the raw material that was used in the manufacture of thorium nitrate in this country. Beginning with 1909, however, monazite began to be imported into this country, increasing in amount each year. In 1910 this amounted to 458,788 pounds, valued at $48,199, and in 1911 to 705,149 pounds, valued at $60,542. This was with a duty of 6 cents per pound on monazite sand containing 5 per cent thoria. Now the duty has been reduced to 4 cents per pound.

While the first shipment of Brazilian monazite sand caused a sharp

decline in the production of monazite in this country, it affected principally the export trade, and this country continued to produce the monazite that was used in this country for manufacturing thorium nitrate.

This last decline, however, has not only caused our export trade in monazite to cease, but also the production of monazite, this being due to the importation of the monazite sand, as well as the thorium nitrate.

The value of the monazite imported is approximately 8 cents per pound, which, with the duty of 4 cents per pound, raises the price on imported monazite to 12 cents, which is the same price that is paid to the miners of monazite in this country for their sand. This, however, has to be refined by the electro-magnetic machinery, which increases the cost and makes it higher than imported sand.

The large imports of monazite and manufactured thorium salts have caused the mines in this country to close, and during the past four years, 1911 and 1912, there was no production of this mineral in the United States.

With the prices of the imported sand and thorium salts remaining as they are, there is but little likelihood of the industry being revived to any great extent. Most of the output of monazite from the Carolinas was from mines owned by farmers, some of whom worked their mines themselves, while others leased their properties to both individuals and corporations. It will be seen from this that the greater part of the revenue from the production of monazite went to the farmers, and they had begun to depend upon it. Thus the closing down of a market for this mineral has worked more or less of a hardship on them.

METALLIC WIRES FOR INCANDESCENT ELECTRIC LAMPS

One of the first metals used in making filaments for incandescent electric lamps was platinum, but on account of the excessive value and scarcity of this metal, carbon filaments soon replaced it. This filament, however, although used almost exclusively for many years and still in use, was and is not entirely satisfactory.

Therefore for many years investigators experimented with various metals in an endeavor to obtain one that could be used satisfactorily as a substitute for the carbon in the manufacture of the filament for incandescent electric lamps. Many metals were used in these experiments, but none of them had all the physical properties desired. It was necessary that the metal be ductile, so that it could be drawn out into very thin wire; that it be able to withstand very high temperatures; and that it should not be brittle. Among the metals tried were uranium, vanadium, titanium, niobium, tantalum, zirconium, osmium, tungsten, and alloys of tungsten and titanium, and tungsten and zirconium.

Tantalum

The use of tantalum in the commercial world began in 1904 and was due to the discovery that this metal is capable of withstanding the highest temperature obtained in an incandescent light, and that it can be obtained of sufficient ductility to permit of its being drawn into very fine wire, which has little tendency to break when heated by the electric current; and it was the first metal to be successfully applied for this purpose. The firm of Siemens & Halske, of Charlottenburg, Germany, who are manufacturers of incandescent lamps, had been investigating for many years the problem of an economical incandescent lamp and had demonstrated that the visible part of the radiation of an incandescent body increases progressively with its temperature; hence it remained but to find an incandescent material that would withstand the highest temperature. The work of the chemical laboratory of this company in solving this problem has been described by Messrs. W. von Bolton and O. Feurerlein,[1] in a paper entitled "The Tantalum Lamp." As stated by Doctor von Bolton, the task resolved itself into finding a metal not very rare nor difficult to procure whose melting point was above 2,000° C., and which could easily be worked to form a filament.

The vanadium group of metals was first experimented with. Neither vanadium nor niobium came up to the requirements of the metal desired, although niobium gave better results than vanadium. Niobium, although having a considerably higher melting point than the vanadium, had a very strong tendency to break up when heated by the electric current. The next metal tried was tantalum, which, in many respects, is very closely related to niobium, and nearly all minerals that contain one are very apt to contain certain amounts of the other. Doctor von Bolton describes the results of his experiments with the tantalum as follows:

I reduced potassium tantalo-fluoride in the manner prescribed by Berzelius and Rose and found that the finely divided tantalum so produced became fairly coherent on rolling, so that by this treatment metallic strips of it could be made. It was also attempted to work tantalum oxide into the shape of a filament by mixing it with paraffin and to reduce it directly into the form of a metallic thread. In these experiments there was observed for the first time a minute globule of molten tantalum, and this globule was of sufficient toughness to permit hammering and drawing into wire. Following out this observation, tantalum powder was melted in a vacuum, and then it was found that the highly heated metal parted with the gases it contained. In this manner I produced my first filaments of pure metallic tantalum, which were, however, very small. When these had been used in lamps with promise of good results, an attempt was made to devise a definite process of purification. The potassium tantalo-fluoride was reduced to metallic powder; this powder contains a small proportion of oxide and of hydrogen, which is ab-

[1]Elektrotech, Ver. Berlin, Jan. 17, 1905, and Western Electrician, Feb. 25, 1905.

sorbed during the reduction. When the powder was melted in a vacuum the oxide and absorbed gas disappeared, and a reguline metal remained; on carefully remelting this, it became so pure that no appreciable impurities could be detected in it.

The chemical properties of this pure tantalum are very remarkable, and some of them are of such a nature as to lead me to suppose that nobody other than myself has ever had metallic tantalum in his hands. When cold, the material strongly resists chemical reagents; it is not attacked by boiling hydrochloric acid, aqua regia, nitric acid, or sulphuric acid, and it is also indifferent to alkaline solutions; it is attacked solely by hydrofluoric acid. Following the behavior of steel when heated in the air it assumes a yellow tint at about 400° C., and the tint changes to dark blue when the tantalum is exposed for some time to 500° C., or for a shorter time to 600° C. Thin wires of the substance burn with low intensity and without any noticeable flame when ignited. It absorbs hydrogen as well as nitrogen with great avidity, even at a low red heat, and forms with them combinations of a metallic appearance, but rather brittle. It combines with carbon very easily, forming several carbides, which, as far as they are at present known, are all of metallic appearance, but are also very hard and brittle. The product which Moissan thought to be tantalum was clearly a carbide of this nature or an alloy of a carbide with pure tantalum, for Moissan himself stated that his metal still contained one-half per cent of carbon. Considering the high atomic weight of tantalum (183), it is obvious that a very small quantity of carbon suffices to carburize a relatively large quantity of tantalum. This view of the constitution of Moissan's product is confirmed by the properties he ascribed to the metal, namely, specific gravity 12.8, great hardness and brittleness. These are not properties of pure tantalum. When in the form of powder, still containing, as previously stated, oxide and hydrogen, the specific gravity of my material is about 14; when purified by fusion and drawn into wire it has a specific gravity of 16.8. It is somewhat darker than platinum and has a hardness about equal to that of mild steel, but shows greater tensile strength than steel does. It is malleable, although the effect of hammering is relatively small, so that the operation must be rather long and severe to beat the metal into a sheet. It can be rolled as well as drawn into very fine wire. Its tensile strength as a wire is remarkably high and amounts to 95 kilograms per square millimeter, while the corresponding figure for good steel is 70 to 80 kilograms, according to Kohlrausch.

The electrical resistance of the material at indoor temperature is 0.165 ohm for a length of 1 meter and a section of 1 square millimeter (specific conductivity as compared with mercury 6.06). The temperature coefficient is positive and has a value of 0.30 between 0° C. and 100° C. At the temperature assumed by the incandescent filament in the lamp at 1.5 watts per candle power, the resistance rises to 0.830 ohm for a length of 1 meter and a section of 1 millimeter. The coefficient of linear thermal expansion between 0° C. and 60° C. is 0.0000079, according to experiments made by the Imperial Normal-Aichungs Commission. Fusion is preceded by a gradual softening, which appears to extend over a range of temperature of several hundred degrees. The specific heat is 0.0365, so that the atomic heat is 6.64, which is in accord with the law established by Dulong and Petit.

As soon as it had been definitely and positively proved that ductile tantalum could be obtained, physical experiments were at once made as to its actual commercial value in the manufacture of an incandescent lamp. It was first confirmed that tantalum does have a very high melting point and that it is but slightly subject to disintegration in a vacuum, even when subjected to a heavy current. From the very first successful experiments were made in the manufacture of a tantalum lamp, and it simply remained for the physical laboratory to perfect the lamp and bring it up to a commercial basis. The results of these experiments have led to an incandescent lamp consisting of a short glass rod carrying 2 disks into which the arms, bent upward and downward in the shape of an umbrella, are cast. The upper star has 11 and the lower 12 arms, each upper arm being in a vertical plane midway between the vertical planes in which two adjacent lower arms lie. Between these two series of arms, which are bent into hooks at their ends, the entire length of the filament of tantalum is drawn in a zigzag fashion. Its extremities, held by two of the lower arms, are connected with the foot of the lamp by means of a platinum strip. As described by Mr. O. F. Feuerlein:[1]

> The standard type for 110 volts, 25 Hefner candlepower, and 1.5 watts per candlepower, has a filament 650 millimeters long and 0.05 millimeter in diameter. The weight of this filament is 0.022 gram, so that about 45,000 lamps contain together 1 kilogram of tantalum. The shape of the glass globe is adapted to the frame described above. Care has been taken to make it of a size not exceeding the usual maximum dimensions of common incandescent lamps of the same candlepower (25 Hefner candlepower, 110 volts). This shape offers a number of noticeable advantages. In the first instance, it is very stable and will stand strong shocks without damage to the lamp. A considerable number of such lamps sent across the sea to test their ability to withstand the hardships of transport came back unhurt, although they had been packed just like common glow lamps, and no special care in any respect had been taken in their handling. The lamp burns, of course, in any position and can therefore be held in any kind of fitting. The light is rather white and agreeable, and its effect is particularly uniform if the lamp is provided with a ground-glass globe.

The life of the tantalum lamp, or the time within which it loses 20 per cent of its initial illuminating power, averages between 400 and 600 hours at 1.5 watts per Hefner candlepower. The absolute life of the lamp amounts to 800 to 1,000 hours under normal working conditions. The illuminating value increases at the beginning, usually after a few hours, by 15 to 20 per cent, and in the same way the consumption of current rises by about 3 to 6 per cent, while the consumption of energy drops to 1.3 to 1.4 watts per candlepower. After this rise of

[1]Loc. cit.

illuminating value, it begins to decrease with a corresponding increase of the consumption of energy.

Another interesting thing regarding these lamps is their behavior when the filament has burnt through. With other incandescent lamps the burning through of the filament would mean that the usefulness of the lamp was at an end. With the tantalum lamp, however, the filament may have been burned through several times without rendering the lamp useless. In some instances such a burning through of the filament is followed by an increase of the illuminating power, this peculiar result being due to the fact that in many cases a broken wire will come in contact with another, thus again establishing the circuit, but at the same time cutting out of the circuit a part of the filament; consequently the lamp burns more intensely. It is possible, if a lamp has a broken filament, to make it again serviceable by simply tapping it to bring the broken piece in contact with another filament. Although tantalum wire, when new, has a greater tensile strength than steel, yet after these lamps have been burning from 200 to 300 hours, the tantalum filament loses to a considerable degree its mechanical resistance and becomes more brittle and will break more easily. Thus, while these lamps are not very sensitive to strong shocks even while burning, care should be taken after the filament has become altered, after burning 200 to 300 hours, that they are not subjected to any severe shocks. While the fresh filament has a perfectly smooth and cylindrical surface, it acquires a peculiarly glistening aspect as it grows old, so that a lamp having served for some time can be readily distinguished from a new lamp. When looked at under the microscope the filament that has burned for a length of time shows a clear tendency toward contraction and formation of drops or beads. This gradual shortening of the filament can also be observed in the lamps themselves and offers a further indication of the age of a lamp.

The tantalum lamp does not require any new fixtures as it fits any socket in which the ordinary incandescent carbon lamp is used.

In 1905 the value of the tantalum lamp was estimated by Dr. Louis Bell[1] as follows:

> The mean result of various tests of lamps were: From clear globes, 22.2 candlepower or 1.85 watts per candlepower, and from frosted globes, 19.08 candlepower at 2.1 watts per candle. It is interesting to note that the clear lamp gives just about one candlepower per inch of incandescent filament, which implies an intrinsic brilliancy of somewhere about 500 candlepower per square inch of filament—a figure much higher than in the ordinary incandescent. As illuminants the lamps are certainly very excellent, but their introduction raises some most interesting questions for the central

[1]American Inventor, July, 1905.

station operator. Putting aside all the petty questions that will be raised about the new lamp for commercial reasons, the broad fact remains that we are here dealing with a bona fide 2-Watt lamp having a life fairly comparable with the carbon filament lamps now customarily in use. Moreover, it is a competitor of these, socket by socket, and not as a substitute, with particular requirements, as in the case of the Nernst lamp, or the very small arcs. There is some doubt as to the life of the tantalum lamp when exposed to unusual vibration, which may perhaps bar it in some special locations, but for the every-day work of the central station there is good reason to believe it generally applicable.

Its price can hardly be said to be fixed in this country, but abroad in Berlin, it is about $1 (four marks), which will give at least a fair line on its commercial results. On this basis, and with power at 10 cents per kilowatt-hour, one finds, taking the new lamp on its 600-hour rating, that the cost of its 12,000 candle hours, including the lamp, amounts to $3.40. The same number of candle hours from a lamp giving a mean efficiency of 3.25 watts per candle would cost $3.90, exclusive of lamps; that is, the consumer could afford to pay $1 for the new lamp better than to take the old ones free. With power as low as 5 cents per kilowatt-hour, the user of tantalum lamps could afford to pay only 75 cents per lamp, as against getting carbon lamps free. This means that a sliding scale of discounts for lamps according to quality could be made to catch the consumer at all prices ordinarily charged for current by central stations.

The lamp was perfected in September, 1903, and a few lamps put on the market in 1904. In the following year, 1905, a larger number of lamps were used, and there began to be a large demand for it, with the result that the number manufactured and placed on the market increased rapidly until 1908, when the tungsten lamp was perfected and placed on the market. In 1909, there was a decided decrease in the demand for tantalum lamps and thus the production of tantalum minerals has gradually decreased. The tungsten lamp has been a very severe competitor with the tantalum lamp, and at the present time is largely replacing it, due to its greater efficiency and the better quality of light that it gives. The tungsten lamp did not entirely replace the tantalum, and it now looks as though there was a place for each of these lamps on the market. A very little tantalum will make a large quantity of wire, and it is readily realized that the production of the tantalum minerals will never be very great for this purpose. A pound of the metal, tantalum, will furnish sufficient wire to make 20,000 20-candlepower incandescent lamps.

The tantalum that is used in this country for making these lamps is manufactured by Siemens-Halske A.-G., of Germany, and it is worth approximately $300 per pound. This company has continued to make investigations regarding new uses for tantalum, and in 1908 it was put forward as a substitute of platinum in the manufacture of many surgical and dentist instruments, and also for use in the manufacture of pens.

A British patent (No. 3691-B) was taken out in 1905 by Siemens & Halske, A.-G., for making pens from tantalum, the specifications for which are partly as follows:

Steel pens have the advantage of great hardness and elasticity, but they do not resist the action of chemicals and, in particular, of that of the atmosphere and of ink. Gold pens, on the other hand, offer great resistance to chemical action, but their mechanical properties are relatively inferior. According to the present invention pens are made of metallic tantalum, a metal that is exceedingly resisting against chemical action and that at the same time possesses a high degree of elasticity and hardness. On account of the great hardness of pens made of this metal, they have also much greater resistance to wear than steel.

The pens can be made either of pure metallic tantalum or of alloys thereof with other metals, and the tantalum can also contain small quantities of other substances, such as carbon, silicon, boron, serving to impart greater hardness thereto.

For the sake of economy, parts of the pens may be made of other materials, such as steel, and only the points, or parts subject to wear or strain, be made of tantalum.

In order to be able to work the tantalum metal satisfactorily, it must previously well fused. By the fusing process it is at the same time freed from impurities and brought to the state of a homogeneous body. The fusing is effected best in vacuo and by means of the electric current. When being mechanically worked, the metal (in particular when it contains a small quantity of carbon or other hardening medium) readily assumes so great a degree of hardness that the further working is rendered impossible, and it must then be carefully reheated or annealed in order to be rendered soft again. In this annealing process care must be taken that the temperature does not rise too high, as otherwise the material is more easily attacked by the oxygen of the atmosphere. In order to prevent too great a heating it is preferable to effect the heating indirectly by bringing large plates or drums to the temperature to which the parts required to be heated are required to be brought, and then to bring the objects of tantalum to be heated in contact with these plates or drums; if, on the other hand, it is desired to raise the tantalum to higher temperatures without being materially affected on its surface, it is of advantage to effect the heating in vacuo, as at very high temperatures the metallic tantalum combines with most substances. The heating in vacuo is preferably effected by electrical means, such as by means of electrical resistances, or directly by passing an electric current through the object to be heated.

In carrying out the manufacture of pens from tantalum metal, the metal having been smelted so as to obtain in the first instance a lump of metal of irregular form, which is in a soft condition, it is worked by rolling, or otherwise, in any suitable known manner into the form of thin sheets, from which the pens are produced by the same means as those employed for the manufacture of pens of other metals. By the said process of rolling the tantalum metal assumes, as before stated, a much greater degree of hardness than before, and it may therefore require to be repeatedly annealed between the several stages of rolling.

After the final stage of rolling, the thin sheets of tantalum metal may be found to be of the right hardness for forming the pens therefrom; if too hard they may be again annealed to a certain extent, or if the pens are required to have a greater degree of hardness than can be attained by merely working the metal, the tantalum may have a small quantity of the beforementioned hardening substances, such as carbon, added to it. This may either be effected in the first instance when the metal is smelted, a very small quantity, such as 0.1 per cent, of carbon being sufficient for the purpose, or the prepared sheets of tantalum metal may be packed in carbon powder and subjected to a considerable heat for some time.

If an alloy of tantalum with another metal is to be employed, the most suitable metals for this purpose are wolfram and iron, either of these metals being simply added to the tantalum metal when in the fused condition. Care must in this case be taken to protect the tantalum against chemical change, for which purpose the melting is preferably effected in vacuo. The composition of such alloys may vary very considerably, but very suitable alloys for the purpose consist of from 95 to 98 per cent of tantalum and from 2 to 5 per cent of wolfram or iron.

Sources of Supply of Tantalum

columbite and tantalite

After tantalum had been proved to be the metal desired for the manufacture of these incandescent lamps, it was necessary to discover or locate a source of supply of this metal. There are quite a number of minerals that contain this metal, which, as has been stated above, is nearly always associated with niobium. Of these minerals, the most common and familiar ones are columbite and tantalite, two minerals that are very closely associated with each other, and are niobates and tantalates of iron and manganese. They pass by almost insensible gradations from a normal columbite, which is the nearly pure niobate, containing about 77.9 per cent of niobium pentoxide and but a trace of tantalum pentoxide, to normal tantalite, which is the nearly pure tantalite, containing about 84 per cent of tantalum pentoxide and only a trace of niobium pentoxide. Columbite is by far the commoner and occurs in the greater abundance. They vary very considerably in specific gravity according to the increase in the percentage of tantalum pentoxide. The nearly normal columbite is 5.3 in specific gravity, while the nearly normal tantalite is 7.8. These minerals occur both massive and crystallized. They crystallize in the othorhombic system, the crystals usually being short, prismatic, or rectangular. A few large crystals have been observed, one from the Ray mine, Yancey County, North Carolina, measuring over 8x2 inches. The cleavage is not very marked, and it breaks with a subconchoidal to uneven fracture. Its hardness is 6, and varies in specific gravity from 5.3 to 7.3, according to its chemical composition. In color it is iron black to grayish and brownish black,

and has a dark red streak. Its lustre varies from a brilliant submetallic to subresinous. Columbites are often iridescent on the exposed surfaces. The general composition is a niobate and tantalate of iron and manganese represented by the formula (Fe, Mn) $(Nb, Ta)_2O_6$, but passing by almost insensible gradation from the normal columbite, Fe Nb_2O_6 to Fe Ta_2O_6, the normal tantalite. There is a mangano-columbite or tantalite, which contains but very little iron.

There is given below analyses of columbites and tantalites that will illustrate the variation in chemical composition and also how the specific gravity increases with the higher percentages of tantalum:

Partial Analyses of Columbite and Tantalite from United States Localities.[1]

Locality	Specific Gravity	Nb_2O_5	Ta_2O_5	FeO	MnO
Branchville, Conn.	5.73	60.70	19.20	12.91	7.03
Branchville, Conn.	6.59	30.16	52.29	.43	15.58
Haddam, Conn.	6.15	51.53	28.55	13.54	4.55
Etta Mine, South Dakota (Black Hills)	5.89	54.09	18.20	11.21	7.07
Etta Mine, South Dakota (Black Hills)	6.37	40.37	41.14	8.28	9.09
Etta Mine, South Dakota (Black Hills)	6.75	29.78	53.28	6.11	10.40
Bob Ingersoll Mine, Black Hills, South Dakota	5.90	57.32	23.43	6 29	13.55
Mitchell County, N. C.		70.98	9.27	12.21	7.30
Yancey County, N. C.	6.88	23.63	59.92	12.86	3.06
Grizzly Bear Gulch, South Dakota	7.77	6.23	78.20	14.00	.81
Henryton, Md.[2]		13.21	38.19	21.42	10.48

[1]Analyses taken from Dana Mineralogy, 6th Edition, 1902, p. 733.
[2]Analysis by chemist of Westinghouse Electric Company of Pittsburgh.

There are a number of other minerals that contain tantalum, some of which might become a source of supply of this metal; but with the known deposits of columbite and tantalite it is doubtful whether there will be very much prospecting carried on for these minerals, as the demand for tantalum must necessarily be limited. There is given below a list of these minerals, together with their chemical composition and localities where they have been found:

OTHER MINERALS CONTAINING TANTALUM

Hatchettolite. This mineral is a tantalo-niobate of uranium with calcium oxide and a small quantity of iron oxide. The percentage of tantalum pentoxide in this mineral is about 29 per cent. It is a yellowish brown mineral, having a resinous lustre and occurs sparingly associated with samarskite at a number of the mica mines in Mitchell County, N. C., principally the Wiseman mine.

Samarskite. This mineral has already been described under the yttria minerals. It contains a much higher percentage of niobium pent-

oxide than tantalum pentoxide. It occurs in considerable quantity at the Wiseman mica mine in Mitchell County, N. C.

Microlite. This mineral is essentially a calcium pyro-tantalate, with a considerable variety of other bases in small quantities. It is a pale yellow to brownish mineral with a resinous lustre, which has been found sparingly in octahedral crystals at Chesterfield, Mass., Branchville, Conn., Amelia, Amelia County, Va., where it occurs in pegmatitic dikes, often associated directly with columbite. The tantalum pentoxide in this mineral is about 68.5 per cent. On account, however, of the scarcity of this mineral, it does not represent one that will be apt to become a source of supply of tantalum. Found sparingly at Ray mine, Yancey County, N. C.

Fergusonite. This mineral has also been described under the yttria minerals. While it usually contains but from 2 to 10 per cent of tantalum pentoxide, occasionally specimens have been found containing as high as 27 per cent of tantalum pentoxide. It does, however, occur in some quantity, and as a source of both yttrium oxide and tantalum, it may become of some considerable commercial value. See page 21.

Tapiolite. This mineral is essentially a tantalate and niobate of iron. It has thus far been observed in but one locality, near the village of Sukala, Finland. It has been observed but sparingly and occurs in pyramidal, tetragonal crystals of a pure black color and a strong adamantine lustre. Its percentage of tantalum pentoxide is 73.9.

Yttrotantalite. This mineral has been described under the yttria minerals. Besides the yttrium oxides, it contains 46.25 per cent of tantalum pentoxide, and is another one of those minerals that might become a source of both the yttrium oxides and tantalum. It is, however, of rather rare occurrence, having been found at but few localities in Sweden, principally at Ytterby.

Hielmite. This rare mineral is essentially a stannotantalate of yttrium, iron, manganese, and calcium, and has been found very sparingly at the Kararfvet mine near Falun, Sweden. Its color is pure black, and it has a metallic lustre. It occurs usually massive, without any apparent cleavage, but occasionally it is in rough, orthorhombic crystals. It contains from 54 to 72 per cent of tantalum pentoxide.

Occurrence of Columbite and Tantalite

These minerals are commonly found in pegmatitic dikes, and the columbite is a very commonly associated mineral in these dikes in the eastern part of the United States. In North Carolina columbite and tantalite have been found in some quantity in the mica mines of Mitchell and Yancey counties, principally the Wiseman mine in Mitchell County, where it occurs as one of the associated minerals of the musco-

vite mica. In the Black Hills of South Dakota, columbite is found in quantity associated with the tin ores that occur in pegmatite. The most noted mines are the Etta and Ingersoll mines (see description beyond). At Branchville, Connecticut, columbite was found in some quantity when the celebrated feldspar locality at this place was being worked for spodumene. The occurrence is a pegmatitic dike.

Columbite and Tantalite Localities in United States

Many localities are known throughout the United States where columbite, which is a mixture of tantalates and columbates occurs in small quantity. In many of the pegmatitic dikes of the New England States, the Carolinas, and the Black Hills, well crystallized specimens of columbite or tantalite, as the mineral is known when it contains a larger proportion of tantalum, have been found, but only in a few of these has the mineral been found in any quantity. The two most promising localities for a commercial source have been in Yancey County, North Carolina, and at several places in the Black Hills of South Dakota.

The first discovery of columbite in America was during Governor Winthrop's term of office.[1] He sent a specimen to Sir Hans Slone, who was then President of the Royal Society. Its exact locality was not known, but supposed to come from somewhere near New London. In 1822 columbite was discovered at Haddam, Connecticut,[2] and a little later about 7 miles from Middletown, Connecticut.

There is given below a brief notice of the occurrences of columbite and tantalite as far as known[3]:

Maine. At Standish, Maine, splendid crystals of columbite occur in granite; also at Stoneham with cassiterite.

New Hampshire. At several of the mica mines of New Hampshire, columbite has been found, as at Plymouth and at Acworth. This occurrence of columbite is in pegmatite.

Massachusetts. At Chesterfield, Massachusetts, well developed crystals of columbite were found in a vein of albitic granite, associated with blue and green tourmaline and beryl. It was also found at Northfield, Massachusetts, associated with beryl.

Connecticut. Two miles from the village of Haddam, Connecticut, columbite crystals, some of which weighed several pounds were found in a pegmatitic vein. It was also found at the chrysoberyl locality and iolite locality at Haddam, Connecticut. Also in a similar occurrence near Middletown, Connecticut, a great many crystals of columbite were found, some of which were quite large. At Branchville, Connecticut,

[1] Dana Mineralogy, 6th Edition, 1892, p. 735.
[2] American Jour. Sci., Vol. IV, p. 52, 1822.
[3] These localities have been taken from several sources, principally Dana Mineralogy, 1892, p. 735.

large crystals and aggregate crystals of columbite sometimes weighing many pounds were found in a vein of albitic granite. It is also found in minute thin tabular crystals upon spodumene at this latter locality.

A feldspar quarry near Glastonbury, Connecticut, contains a certain amount of columbite and other tantalum minerals.

New York. At Greenfield, associated with chrysoberyl.

Pennsylvania. At Mineral Hill, near Middletown, Delaware County.

An interesting occurrence of a tantalum mineral has recently been discovered at the feldspar quarry of Mr. W. F. Patterson, Jr., at Henryton, Carroll County, Md., about 28 miles from Baltimore. It occurs in irregular masses and rough crystals in the feldspar, and during 1903 a considerable amount of this material was encountered in quarrying, but it was all thrown over the dump, as no one realized what the mineral was or its value. A specimen, however, was sent to the Westinghouse Electric Company at Pittsburg, and a partial analysis by its chemist gave the following result:

ANALYSIS OF TANTALUM MINERAL FROM HENRYTON, MD.

Tantalic oxide (Ta_2O_5)	38.19
Niobic oxide (Nb_2O_5)	13.21
Manganese oxide (MnO)	10.48
Ferric oxide (Fe_2O_3)	21.42
Silica (SiO_2)	12.98

This analysis shows that the mineral contains both tantalic and niobic acid, with a considerably higher per cent of the former. On account of the high atomic weight of the tantalum, the molecular ratio of the tantalic acid to the niobic acid is approximately 3.5 to 2. It may be that the material analyzed has a certain amount of feldspar mixed with the tantalum mineral, which would account for the high percentage of silica.

Virginia. Near Amelia Courthouse, Amelia County, Virginia, splendid crystals of columbite have been found in a pegmatitic dike, associated with allanite, fergusonite, monazite, etc. This property has been worked for mica.

North Carolina. Columbite crystals in parallel position with samarskite crystals have been found at the Wiseman mica mine, Mitchell County. It also occurs sparingly in small crystals at the Deake and other mica mines in Mitchell County. At the Ray Mine, near Burnsville, Yancey County, some very large well developed crystals of columbite have been obtained. The occurrences of columbite in these localities are in pegmatitic dikes. Columbite has also been found in North Carolina near Franklin, Macon County; White Plains, Alexander County; Balsam Gap mine, Buncombe County; and Brindletown, Burke County. Massive tantalite occurs in some quantity near Mine Fork, Yancey County.

Alabama. Near Rockford, Coosa County, massive tantalite has been found in some quantity.

South Dakota. In many of the mica and tin mines of the Black Hills, South Dakota, columbite has been found in some quantity; as the Etta mine (see description below); the Peerless mine, one-half mile north of the Etta; the Ingersoll mine; Grizzly Bear Gulch, two and a half miles southwest of the Etta mine; and Laughing Water Creek, north of Custer. The occurrence of the columbite is for the most part in pegmatitic dikes that have been worked either for tin or for mica. The principal localities where it occurs in quantity are the Etta and Ingersoll mines in Pennington County. At the latter a mass of columbite was found that weighed 2,000 pounds.[1]

The Etta mine[2] is located one-half mile south of Keystone in a large mass of very coarse pegmatite that had been intruded into the schist of the district. The dike is about 150 to 200 feet wide and now forms the summit of a round hill that rises about 300 feet above the valleys. The mine is noted for the very large size of the crystals of several of the minerals that occur in the dike. Some spodumene crystals in this mine have been observed that reached a length of 35 feet, with a cross-section of approximately 3 x 6 feet. This mineral is mined for the lithia that it contains. Cassiterite has been found in rough crystals or masses, weighing a number of pounds each. The feldspar also occurs in large masses, and it is associated with these huge masses of feldspar that the columbite occurs in the larger crystals or masses. At the Etta mine one mass of columbite was reported that weighed 600 pounds. The columbite deposits of the Black Hills are the ones that have furnished the greater amount of the columbite that has been produced and marketed in this country. The columbite from the Etta mine has been analyzed by Mr. W. P. Headden,[3] who made a series of analyses of this mineral. There is given below the columbium and tantalum determinations of several of the specimens analyzed, together with their specific gravity:

PARTIAL ANALYSES OF COLUMBITE FROM ETTA MINE

	Specific Gravity	Cb_2O_5	Ta_2O_5
1	5.89	58.09	18.20
2	6.18	47.05	34.04
5	6.515	39.94	42.96
6-a	6.612	35.11	47.11
7-b	6.707	31.31	52.49
8	6.75	29.78	53.28

[1]Amer. Jour. Sci., Vol. XLI, 1884, pp. 340-341.
[2]U. S. Geol. Survey, Bull. 380, 1909.
[3]Amer. Jour. Sci., Vol. XLI, 1891, p. 95.

The above analyses show wide variation of the columbic and tantalic acids in the columbite, and in selling the minerals it is necessary to know the percentage of the tantalic acid in the mineral. It is possible to get an approximate per cent of the tantalic acid by taking the specific gravity of the mineral.

Some material was obtained from Tinton, South Dakota, which was treated at the United States Geological Survey concentrating plant at Portland, Oregon. The concentrates of this material obtained on the Wilfley table consisted principally of cassiterite, scheelite, and a heavy black mineral which gave, upon analysis, 44 per cent tantalic oxide and 30.5 niobic acid.[1] The specific gravity of the mineral was 6.8.

Colorado. In the Pike's Peak region columbite has been found on microcline, and also occurs at Turkey Creek, Jefferson County.

California. Columbite has been reported from Kings Creek District, Fresno County.

Idaho. Tantalum minerals (probably columbite) have been reported by Victor C. Heikes[2] of the U. S. Geological Survey to have been found in the gravels of Snake River.

Nearly all of the tantalum ore has been obtained from Western Australia, where the ore is principally a manganotantalite, carrying 80 per cent or more of tantalum oxide.

Production of Tantalum Minerals

As will be seen from statement given below in regard to the production of tantalum minerals in the United States, this particular industry has never become of any large value. Considering the fact that sufficient tantalum wire could be obtained from one pound of tantalum for use in the manufacture of over 20,000 lamps, the production of crude ore for this particular use of tantalum would never be very large. Another illustration is that 100 pounds of tantalum will make 4,921,250 feet of wire, such as used in the manufacture of the tantalum lamp, and is worth approximately $430 per pound. None of the ore thus far produced in this country has been utilized here for the production of tantalum, but has all been shipped abroad to Siemens & Halske, A.-G., of Charlottenburg, Germany. This firm is the only one so far as known that is producing tantalum for use in the manufacture of wire and other purposes. Most of the ore is produced from Green Bush and Pilbara districts of Western Australia. These ores, which are stibiotantalite (a tantalate of antimony), tantalite (iron tantalite), and manganotantalite (a tantalate of manganese), carry a higher percentage of tantalum than the American ores, which are usually columbite.

[1]Determinations made by Dr. W. F. Hillebrand, U. S. Geol. Survey.
[2]Mining Review, Aug. 30, 1905.

In 1904 there was a small production, perhaps a few hundred pounds, of columbite from South Dakota, most of which was shipped abroad. In 1905 the production was still smaller.

In 1906 the total world production of tantalum ores was something over 81 tons; but only this amount, valued at $51,173, was reported sold during that year on account of the lack of demand. Of this production only a small amount was produced in the United States.

In 1907 only a few hundred pounds of columbite were produced, which were mined principally in South Dakota, with a very small amount from North Carolina. It was all shipped to France.

In 1908 there was no production reported in the United States, and the world production was valued at only $1,946.60.

In 1909 a few tons of columbite were mined near Keystone, South Dakota, by the Western Reduction Company, of Omaha, Nebraska, who were operating a mine for amblygonite; but there was no record of this being sold.

In 1910 a few hundred pounds of columbite were mined at Keystone, South Dakota, by Emil E. Hesnard, and Canyon City, Colorado, by E. E. Smith. None of it, however, was sold during the year.

In 1911 a few hundred pounds of columbite were produced by Emil E. Hesnard of Custer, South Dakota, from a deposit at Keystone, but this was sold for mineralogical specimens and none of it was used for reduction to metal.

In 1912 there was no production of tantalum mineral reported in the United States for any purpose.

There has been imported each year into this country tantalum wire for use in the manufacture of tantalum lamps.

PRODUCTION OF COLUMBITE IN NORTH CAROLINA

As is seen from the above, there has only been a very small production of tantalum minerals in North Carolina and that was during the year 1907. The production was of the mineral columbite and was from Spruce Pine, Mitchell County, amounting to an unknown quantity, which was, however, only a few pounds.

Tungsten

As stated above, tantalum did not give entire satisfaction as the filament for incandescent lamps; and, while this lamp was being placed on the market, experiments were continued with other metals to obtain a still better filament for the electric incandescent lamp. The result was that in 1907 another lamp was perfected in which the filament was made of tungsten.

The preparation of pure tungsten is a difficult matter,[1] and there is considerable secrecy maintained in regard to the methods employed in obtaining the pure metal. In a general way it may be said that the metal is obtained by fusing wolfram with sodium carbonate, obtaining the tungsten in the form of sodium tungstate. This is treated with a strong mineral acid, which forms a tungstic oxide. When the mineral scheelite is used, it can be treated directly with the mineral acid, giving the tungstic oxide. The oxide is then mixed with carbon and strongly heated in crucibles, the tungsten being then obtained as a metallic powder containing some carbon. The oxide has also been reduced electrically.

When the tungsten lamp was first put on the market, there were several objectionable features: (1) there was a very high percentage of breakage during transportation and also while the lamp was being used; (2) it had to be burned in a vertical pendant position; (3) there was considerable blackening of the globes; and (4) the filament was apt to burn out in a comparatively short time.

In October, 1907, the Engineering Experiment Station of the University of Illinois purchased 12 tungsten lamps (40-watt size), which was the smallest obtainable lamp at that time, at a cost of $1.50 each. These were shipped by express, but when received only five of the twelve had unbroken filaments, and the five they tested had an average life of only 50 or 75 hours. As far as could be determined, this was a typical experiment with the tungsten lamps, when first introduced. The manufacturers, however, realized that the tungsten filament would give satisfaction, and all the companies interested made a special effort to overcome the faults of the lamp referred to above.

At the present time, there are several types of tungsten lamps on the market that differ principally in the method of manufacture of the filament, and the scheme of mounting the filament. Some of the principal methods of preparing the tungsten filament are described below[2]:

Four methods employed in preparing the filament from tungsten to be used in the manufacture of the lamp are: (1) The paste or Auer process; (2) the deposition process; (3) the colloid process; and (4) the amalgam process.

(1) The paste or Auer process is similar to the one used in making ordinary carbon filaments, and consists of the mixing of finely powdered tungsten and considerable binder, such as sugar or some other organic substance, and then squirting under great pressure this resulting paste through a diamond die. In order to remove the carbon and the binder material, the moist filament is heated in an atmosphere of steam and hydrogen, which leaves an almost pure tungsten filament.

[1]Min. Res. U. S. Geol. Survey, 1906, p. 524.
[2]Bull. 33, University of Illinois, March, 1909, pp. 5-7.

(2) In the deposition process a fine filament of carbon is heated in an atmosphere of some tungsten compound, as the oxychloride of tungsten This causes the metal to be deposited as a shell upon the carbon core, which are made to unite by the application of heat to form the tungsten carbide. This in turn is reduced and the carbon removed by a similar method as used in the paste process.

(3) The colloid process consists of the formation of a colloidal tungsten by maintaining an arc between tungsten electrodes under some liquid, which may be water; or by reducing tungstic trioxide with potassium cyanide. A plastic colloidal mass is obtained, which, after being brought to the proper consistency, is squirted through a die to form a filament similarly as in the paste process. The filament obtained is then dried and gradually brought to a white heat in a nonoxidizing atmosphere, which converts the tungsten into the crystalline state.

(4) In the amalgam process[1] amalgam is made of tungsten with cadmium, and this is then squeezed through a die into filament. These filaments are then heated by electric current in a vacuum, which expels all traces of the cadmium and mercury.

The first three processes described are the ones most in vogue for making tungsten filament. There is considerable variation in the character of the filament made by the different processes and its effect upon the life and value of the tungsten lamp.

One American firm (P) makes their tungsten filaments by the paste or Auer process, and mounts the filament in the lamp by four hairpin loops, connected in series and mounted upon supporting spires. The loops are connected at the base end of the stem by fusing together the filament and spires. In order to allow for contraction that takes place after these filaments have been burned for sometime, they are hung loosely on the spires. The length of the filament is 19.27 inches, and is .00163 inch in diameter. This would give a total surface area of .0987 square inch.

Both the deposition and colloid processes are used by German manufacturers in making their filaments. One German Company (D) employed the deposition process, using a filament 15.92 inches long, which had a diameter of .00202 inch, and a surface area of .1009 square inch. The filament in the lamp consists of four loops, similarly as in the American lamp, but the supporting spires at the tip end of the stem are very thin and flexible springs, which, by their action, keep the filament under a slight tension. Flexibility of the spires permits contraction of the filament to take place after the lamps have been in use for sometime. The filaments and spires are connected by means of pasted joints

[1]Min. Res. U. S. Geol. Survey, 1906, p. 524.

at the base end of the stem. The entire glass stem, which carries the filament, is mounted between two coil springs, which are supposed to absorb the jar and vibration to which the lamp may be subjected either in transportation or while in use, and thus prevent breaking of the filament.

Another German tungsten lamp (C), in which the filament is made by the colloid process, has the filament in 4 loops, each of which is mounted in a peculiar spiral shape and hung loosely enough to permit of contraction. Connections are made by fusing together the filaments and spires at the base end of the stem. In this lamp the length of the filament is 19.87 inches, and its diameter is .00138 inch, having a surface area of .0859 square inch.

The Engineering Experiment Station of the University of Illinois has made a rather elaborate investigation of these lamps, from which they have obtained some very interesting results. The conclusions drawn from their experiments are given below[1]:

Comparisons of the durability of filaments made by the colloid, deposition, and paste processes are very difficult to make owing to the fact that the three types were all mounted differently. Undoubtedly the manner of mounting a filament has a great effect upon its life, and whether the superior life of one type of lamp is due to the fact that it has a better scheme of mounting or to the fact that the process of manufacture is better, can hardly be decided definitely from these tests. Tests of filaments made by the three processes and mounted in exactly the same way would be necessary to decide this question absolutely. From the tests just described, however, the colloid process seems to give a filament that is less durable than the other two. It is true that when tested under condition B, it gave a longer life than did the D lamp, but this was because its construction enabled it to withstand vibration better rather than because of the superior quality of the filament. Under condition A, where vibration was eliminated and where the scheme of mounting had less effect upon the life, the D lamp gave a considerably longer life. The P lamp gave a much better life under both conditions of operation than the C and D lamps. This must be due at least in part to the fact that the filament has better lasting qualities than those made by the other processes. Under condition A, this lamp shows the same superior life as it did under condition B, where differences in mounting produce great differences in average life.

Of the three schemes for mounting the filaments, that of the C lamp undoubtedly holds the filament more nearly in the desired place for all positions of burning than the other two. While holding it in the proper position, it at the same time holds it loosely enough so that all necessary contraction can take place without putting it under a tension that is likely to cause it to respond readily to vibrations. The principal defects of this scheme of mounting are that it lacks simplicity and that there are a large number of supporting spires that carry off by heat conduction energy that should be radiated in the form of light. For burning in a vertical pendant

[1]Bull. 33, University of Illinois, 1909, p. 31.

position or nearly so, the mounting of the filament in the P lamp is very good. The filament is held loosely so that contraction can take place without putting it under sufficient tension for vibration to have the serious effect upon it that it does upon the D filament. When burning horizontally it sags considerably, often enough to allow it to touch the glass stem supporting it. This at least gives the lamp a poor appearance even if it caused no other bad effects. The mounting of the D filament permits almost no distortion of the filament to take place when burning horizontally, but it has the serious fault of holding the filament in tension so that it responds readily to vibrations. The spring suspension of the supporting stem tends to make worse the very thing that it is intended to prevent. No doubt there would be less trouble from vibration with this style of filament mounting if the stem were rigid. That there would still be bad effects from vibration, even if the stem were rigid, is proved by the P lamp. When a filament section in this lamp, which has a rigid stem, contracted sufficiently to put it under tension, as sometimes happened, it would respond to vibrations when burning under condition B in the same way that the D filament did, and then quickly fail. A considerable number of the newer tungsten lamps coming on the market have their filaments mounted under a slight tension, just as in the D lamp, but where they are to be subject to vibration, it is doubtful if they will give as good results as more loosely strung filaments would.

These tests show that the performance of tungsten lamps may vary to a surprising degree, depending upon the kind of lamps used and upon the conditions under which they are burned. Some lamps will give as high operating cost as the old carbon lamps while burning under certain conditions, whereas other lamps will give good results under those same conditions. Under the best conditions, however, the tungsten lamps now on the market give excellent results. Their efficiency is maintained in a remarkable way and the life is very long, often several times what they are advertised to give.

Breakage in shipment and handling have been reduced to a small fraction of what was common in the early lamps. Only three of the three hundred lamps which were purchased for these tests were received with broken filaments, and although the lamps on some of the tests which have been described were handled dozens of times, almost no trouble was experienced so far as the breakage of filaments was concerned.

The other defect of the early lamps, that of early blackening of the bulbs, seems to have been overcome. Not one of the lamps on the tests showed any early discoloration at all; in fact, not until after about 600 hours of burning did any of the bulbs show an appreciable amount of blackening.

One difficulty encountered in preparing the tungsten filament was to obtain a wire sufficiently fine for lamps of small candle power as at first it seemed impossible to drill small enough holes through diamonds to make this wire. Now, however, it is possible to draw wire in quantity of 0.0006″ in diameter.[1]

The objectionable features of the tungsten lamp have been practically overcome, so that now this lamp stands as one of the best of the incandescent lamps. At its introduction, the whiteness of this light, its high efficiency, about 1¼ watts per candle, as compared with 3.1 watts per

[1]U. S. Geol. Survey, Min. Res., 1911, pt. 1, p. 945.

candle for the mineral carbon lamp and 2 watts per candle of the tantalum lamp, the long life of the tungsten filament being of use in an alternating or direct current, made the lamp very acceptable, and even with its drawbacks, it found great favor. In 1909 and 1910 most wonderful improvements were made in the manufacture of the tungsten lamp which has very greatly increased its usefulness, and therefore a demand for it. Through a process devised by the General Electric Company, tungsten can be drawn into a fine wire that is about as strong as a steel wire, which, of course, means that the lamps can be shipped with a very small loss of breakage of the filament, and this has made it possible for railroad trains and automobiles to use these lamps. This strengthening of the filament has made it possible and practicable to manufacture lamps of greater candle power.

The melting point of tungsten is 3,090 C., as determined by Dr. C. W. Widener and Dr. G. K. Burgess of the Bureau of Standards, Washington, D. C. They determined the melting point of tantalum as 2,910 C.

The economic value of the tungsten lamp has been well illustrated in a paper by Dr. W. R. Whitney,[1] Chief of the Research Laboratory of the General Electric Company, who, in commenting on the economy obtained in the use of the incandescent lamps as compared with the lamps used ten or twelve years ago states:

> On the assumption that the present rate of lamp consumption is equivalent to about eighty million 25-watt tungsten lamps per year, and on the basis of 1¼ watts per candle power as against 3.1 of the earlier lamps and of charging power at 10 cents per kilowatt hour, we get as a result a saving of $240,000,000 per year, or two-thirds million per day. Naturally, this is a saving which is to be distributed among producers, consumers, and others, but illustrates very well the possibilities.

In 1906 a patent was issued to Mr. G. Allen Heany for a tungsten-titanium alloy lamp, whose melting point and efficiency are said to be higher than that of a tungsten. This lamp has not, as yet, however, played any important part in the incandescent lamp industry.

Tungsten alloyed with zirconium[2] is reported to form the filament of a German incandescent lamp capable of standing 220 volts and having an efficiency of 1.2 to 1.3 watts per candle power per hour. There is no report of this lamp having been placed on the market. These lamps, however, as far as can be judged, are not equal to the tungsten lamp.

The quantity of tungsten ores used in the production of metallic tungsten for use in the manufacture of filaments for incandescent lamps is comparatively small (amounting to only a few tons per year), as one

[1] Paper read before the Technology Congress at the Mass. Inst. of Technology, 1911; and U. S. Geo. Survey, Min. Res., 1910, pt. 1, p. 742.

[2] U. S. Geol. Survey, Min. Res., 1906, p. 524.

pound of tungsten will make an enormous amount of wire. The minerals from which tungsten is obtained are wolframite, hübnerite, and scheelite, the iron, manganese and calcium tungstates respectively.

Sources of Supply

Tungsten, which was formerly considered one of the rather rare elements, has been proved to occur in large quantity and to be rather widespread in its occurrence. The minerals which constitute the ores of tungsten are:

1. *Wolframite.* This is a dark gray, grayish black, to deep brownish black mineral with a submetallic to resinous lustre. Its specific gravity is 7.2 to 7.5, and its hardness 5 to 5.5. The mineral crystallizes in the monoclinic system and is often found in terminated crystals. It is very brittle, having a perfect cleavage parallel to the pinacoid face, but an uneven fracture. It is more commonly found massive with a more or less granular structure. The chemical composition of the mineral is a tungstate of iron and manganese (Fe Mn) WO_4. It fuses easily before the blowpipe to a globule having a crystalline surface, which is sometimes magnetic. The high specific gravity of this mineral is very noticeable, and if it is in pure masses, the specific gravity will be of considerable assistance in identifying the mineral. This property, together with its dark colored streak, with a brownish or reddish tinge, its hardness, and the fact that it is easily fusible, should be the means of readily identifying it and prevent confusing it with other minerals such as magnetite, hematite, rutile, cassiterite (tinstone), titanic iron, tourmaline, etc.

2. *Hübnerite.* This mineral is very similar to wolframite, but usually occurs in bladed forms and has a decided brownish red to nearly black color, while the former is more commonly grayish black. Its chemical composition differs from that of wolframite in that the iron has been largely replaced by manganese, and it is essentially a manganese tungstate, $MnWO_4$. It is less fusible before the blowpipe than wolframite and gives a very strong manganese reaction with either sodium carbonate or borax.

3. *Scheelite.* This is a very heavy, white to yellowish white mineral, with an adamantine to vitreous lustre. Its specific gravity is 5.6 to 6.1, and its hardness is 4.5 to 5, it being readily scratched by steel. It crystallizes in the tetragonal system, but is more commonly found massive. Its chemical composition is calcium tungstate, $CaWO_4$. Before the blowpipe scheelite fuses with difficulty to a semitransparent glass. It is readily decomposed by hydrochloric or nitric acids, leaving a yellow powder which is soluble in ammonia. There are a number of minerals

which in appearance are very similar to scheelite, these being cerussite, a carbonate of lead; anglesite, a sulphate of lead; barite or barytes, a sulphate of barium, and witherite, a carbonate of barium. These minerals can all, however, be readily distinguished from scheelite by simple chemical tests, as the two lead minerals and the barium carbonate are readily fusible, and the two barium minerals give readily a green flame, due to barium oxide, when heated before the blowpipe. The scheelite is so much heavier than either of these two barium minerals that its specific gravity alone, if one is familiar with the scheelite, should readily prevent any confusion. The two lead minerals are so apt to be associated with galena that it is doubtful if there would be very much tendency to confuse them. The best method of familiarizing one's self with these tungsten minerals is to obtain specimens of each one. This applies especially to those who intend to prospect for them.

Besides these three minerals, which up to the present time have been the sources of supply of the metal tungsten, there are a number of other minerals which contain a considerable percentage of tungsten, but have thus far been found only in small quantities and at a few localities. These minerals are: Cupro-tungstite, a tungstate of copper, $CuWO_4$, which passes into a tungstate of copper and calcium, $(CaCu)WO_4$, and is a highly vitreous mineral of pistachio-green color, occurring in crusts; stolzite, a lead tungstate, $PbWO_4$, found sparingly in tetragonal crystals, of a green to brown or red color; tungstite, or tungstic ocher, a trioxide of tungsten, WO_3, which occurs with wolframite at a number of localities where the tungstite has been found filling small cavities in the wolframite, or cutting it, and has very probably resulted from its decomposition, a pulverulent and earthy mineral of a bright yellow to yellowish green color; and meymacite, a hydrated tungsten oxide formed from the alteration of scheelite.

Occurrences

The first demand for the metal tungsten was supplied by tungsten ores from Cornwall and Cumberland, England. With the increasing demand for the metal, other deposits were soon located; and before there was any development of any tungsten properties in the United States, these ores were being obtained from England, Austro-Hungary, Saxony, Germany, and Australia, and at that time what tungsten was used in the United States was imported. About 1900 considerable interest was aroused among prospectors and others in this country regarding the occurrence of tungsten minerals, and sufficient deposits of these minerals were soon discovered to supply a great deal more ore than demanded by the home consumption.

The general occurrences of tungsten can be divided roughly into three general groups somewhat as follows:

(1) Those in which the tungsten minerals are more or less closely associated with ores of tin in greisen and as constituents of pegmatitic dikes. Deposits of this character have been found in Cornwall, England, and in the Black Hills, South Dakota.

(2) Deposits in quartz and related veins that have been found in granite and rocks of similar character and that are in no way associated with tin ores. Veins of this character are those in the Dragoon Mountains of Arizona, near Osceola, Nev., etc.

(3) Tungsten ores associated with limestone, as those near Lead, S. Dak.

No strong line of demarcation can always be drawn between these groups, and very often they so grade into each other that an occurrence can sometimes be ascribed to two of the groups.

The greater number of the localities where these minerals have been found are in the Western States, the principal deposits being in Arizona, Nevada, and Colorado. The other Western States in which tungsten deposits have been found, although worked to but a small extent, are Idaho, Montana, New Mexico, Oregon, South Dakota, and Washington. In the Eastern States the principal deposits are located in Connecticut, and a very small quantity has been found in North Carolina.

TUNGSTEN IN NORTH CAROLINA

Tungsten minerals have been known to occur in North Carolina for a good many years and have been found in connection with some of the gold ores. At the time these minerals were discovered they had no value except as mineralogical specimens, and so no special attention was called to the localities where they occurred. Scheelite has been found at the following mines in Cabarrus County: at the Flowe mine, where it occurs in yellowish crystals; at the Cosby mine, where yellowish crystalline masses of considerable size were found; and at the Cullen mine, where it has been observed in rounded granular patches of a grayish yellow color. Wolframite has also been found associated with the scheelite at all these mines, but from what information can be obtained the scheelite predominates. No work has been done at these mines for the tungsten minerals, and it is not known whether or not they occur in quantity.

Uses of Tungsten

Metallic tungsten has been obtained in the form of a metallic powder of a bright gray lustre which is sufficiently hard to scratch glass. In this form the metal is not changed by moist or dry air and at red heat

it burns in the air to the trioxide. In 1781 the Swedish chemist, Scheele, proved that the mineral called wolframite contained a new mineral acid, to which the name tungsten (wolfram) was finally given.

The uses of tungsten are varied, and the principal ones are in the manufacture of the alloys[1], ferro-tungsten and aluminum-tungsten. Until recent years about the only uses of tungsten were in the preparation of salts used to make colored cotton goods fast or washable and to make clothes used for theatrical and other purposes noninflammable. It was also used to a certain extent in the manufacture of stained and other papers.

The use of ferro-tungsten in the manufacture of steels[2] is becoming an industry of considerable importance. The tungsten makes the steel exceedingly hard and tough, and steel so treated is believed by many to be superior to any other steel manufactured. Projectiles made out of tungsten steel have penetrated through 14 inches of the best armor plate. It is also beginning to be used in the manufacture of tool steel and spring steel. Tools made of tungsten steel can be driven much faster in cutting other metals, and the tungsten spring steel has more carrying power than that made out of ordinary steel. It is also being used in sounding plates and wires for pianos, to which it gives additional strength and quality.

Incandescent lamps have been made of other metallic filaments than those described above, but, up to the present time, they have not become of any particular commercial importance and therefore only a brief notice is given of them in this paper.

Titanium

One of the main difficulties experienced in the manufacture of a titanium incandescent lamp has been the reduction of titanium to a metal. One reason why this metal is of particular interest for the filament is that its melting point is said to be 200° C. higher than tungsten and with a higher electrical resistance. This would make the efficiency of the titanium filament in an incandescent electric lamp higher than the tungsten filament.

From 1906 to 1909 several manufacturers carried on rather extensive experiments in regard to the manufacture of titanium incandescent lamps, but with the exception of a reported manufacture of 1,000 lamps by a firm during 1906,[3] there have been no lamps to any extent placed on the market and this lamp has not yet reached a commercial stage.

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[1]See Sixteenth Ann. Rept. United States Geological Survey, Part III, p. 615.
[2]Jour. of Iron and Steel Institute, No. 1, 1895.
[3]U. S. Geol. Survey, Min. Res., 1906, p. 530.

There is a use for titanium in lighting apparatus that gives considerable promise of being commercially successful and that is in the manufacture of electrodes for arc lights. As early as 1878, Thomas A. Edison took out a patent in England for the use of titanium oxide in arc lights. Several other patents have been issued since that time, some of which relate to the use of titanium oxides and others to titanium carbonate. The General Electric Company[1] has made arc lamps using both the titanium carbonate and titanium oxide electrodes. In these lamps only one of the electrodes is made of the titanium compound, the other being a carbon electrode. In some of the lamps made by this company, one electrode was made of titanium oxide with a certain amount of magnetite.

Sources of Supply

Titanium is obtained principally from the mineral rutile with smaller amounts from the mineral ilmenite or menaccanite.[2]

RUTILE.[2]

Rutile crystallizes in the tetragonal system commonly in prismatic crystals vertically striated or furrowed; often slender acicular. It is also compact, massive to coarse and fine granular. Twinning is frequent and of several kinds. Cleavage distinct; fracture subconchoidal to uneven. Brittle. Hardness 6 to 6.5. Specific gravity 4.18 to 4.25; also to 5.2 in a black variety containing 10 per cent FeO. Lustre, metallic-adamantine. Color reddish brown, passing into red; sometimes yellowish, bluish, violet, black, rarely grass-green. Streak, pale brown. Transparent to opaque.

The chemical composition of rutile when pure is TiO_2, corresponding to oxygen 40 per cent, titanium 60 per cent. A little iron and vanadium are usually present, the former ranging up to 10 per cent; less often a little chromium and tin. Rutile is insoluble in acids, and infusible before the blowpipe. Molecular weight, 80.1; molecular volume, 19.1.

Rutile occurs in igneous, metamorphic, and sedimentary rocks. In igneous rocks it occurs both as a pyrogenetic constituent and as an alteration product. It is common in the metamorphic rocks, such as geisses, mica schists, amphibolites, and phyllites, and sometimes in granular limestone and dolomite.[3] It also occurs in some sedimentary rocks, in some rocks produced by contact metamorphism, and in veins both metalliferous and nonmetalliferous.[4] According to Emmons[5] rutile is

[1]U. S. Geol. Survey, Min. Res., 1908, pt. 1, p. 745.
[2]Bull. III A. Va. Geolog. Survey, 1913, pp. 6, 7, 8.
[3]Iddings, J. P., Rock Minerals, New York, 1906, p. 498.
[4]Winchell, N. H. and A. N., Elements of Optical Mineralogy, New York, 1909, p. 347.
[5]Emmons, W. H., A Genetic Classification of Minerals, Econ. Geology, 1908, vol. III, p. 621.

formed in igneous rocks, in pegmatite dikes, in contact metamorphic deposits, in deposits of the deep vein zone, and as a product of dynamo-regional metamorphism.

Rutile is formed as a secondary mineral, derived from ilmenite and titanite, and sometimes from certain ones of the ferromagnesian silicates, especially biotite. It is relatively a very stable mineral, but sometimes alters to leucoxene and is sometimes accompanied by the formation of ilmenite.

Rutile has been found in many localities throughout the United States, but there are very few where it is found in any great amount and, at the present time, there are only two localities, one in Virginia and one in Pennsylvania, where it occurs in commercial quantity.

In Pennsylvania it is found in the central portion of Chester County and this locality furnished the few hundred pounds required annually for the dental trade and the production was obtained from this locality until the opening of the Virginia deposits in 1901.

The principal locality in the United States where rutile is found is near Roselands, Nelson County, Virginia, near which are located the works of the American Rutile Company and the General Electric Company. The mineral occurs disseminated through a coarsely crystalline granitic rock which has been mined by means of open cuts. The rock is crushed and the rutile usually concentrated.

ILMENITE.[1]

Ilmenite is a heavy, black mineral crystallizing in the hexagonal system. It is rarely seen in good megascopic crystals in rocks, but usually occurs in embedded grains and masses, sometimes in plates of irregular to hexagonal outline, and loose as sand. Cleavage not developed. Fracture conchoidal; brittle. Color iron-black, sometimes with faint reddish to brownish tinge; lustre metallic to submetallic; streak black to brownish-red. Opaque. Hardness 5 to 6; specific gravity 4.5 to 5. Slightly magnetic, but variable.

The chemical composition of ilmenite is variable. If normal the mineral is expressed by the formula FeO, TiO_2, corresponding to FeO, 47.3 per cent, TiO_2, 52.7 per cent. There is an isomorphous series $(Fe, Ti)_2O_3$ with variable amounts of iron and titanium grading to hematite. Sometimes contains magnesium replacing ferrous iron. Many analyses of ilmenite do not correspond to the formula given above, but approximate more closely to the one suggested by Rammelsberg, $FeO.TiO_2.nFe_2O_3$. Recent studies of ilmenite from some localities suggest that the ferric oxide present in the mineral is not in chemical combina-

[1]Bull. 3, Va. Geolog. Survey, 1913.

tion, but is mechanically admixed as inclusions or intergrowths of hematite. Very difficultly fusible before the blowpipe; becomes magnetic in the reducing flame. Fused with sodium carbonate, dissolved in hydrochloric acid, and the solution boiled with tin, becomes violet, showing titanium. Difficultly soluble in acids; decomposed by fusion with bisulphate of potash. Molecular weight, 152; molecular volume, 30.4.

Ilmenite is a widely distributed mineral, occurring as a common constituent in igneous rocks from granite to gabbro and related rocks and their lava forms. It occurs in these rocks in the same manner as magnetite which it often accompanies. It is similarly found in many metamorphic rocks, especially gneiss, mica-schist, and amphibolite. According to Lindgren[1] and Emmons[2] ilmenite is formed in igneous rocks, in pegmatites, in contact metamorphic deposits under regional metamorphic conditions, and in deep veins. Ilmenite in rocks closely resembles hematite and magnetite, and unless the grains are of such size that they can be safely tested, the discrimination of these minerals in rock sections is not always possible. The most important occurrences of ilmenite are in the coarser grained gabbros and anorthosites where the mineral is very common, and is not infrequently segregated in places into large masses.

Ilmenite in rocks commonly alters to a whitish, yellowish, or brownish aggregate, which is highly refracting and when transparent, highly double refracting, usually called leucoxene, sometimes titanite. It alters sometimes to carbonate with the separation of rutile, a change which appears to be confined to certain phyllites.

Other minerals containing titanium are given in the table below together with the theoretical amount of titanium oxide.

LIST OF TITANIUM MINERALS[3]

Mineral	Composition	Contains TiO_2 Per Cent
Oxides:		
Rutile	TiO_2	100
Octahedrite (anatase)	TiO_2	100
Brookite	TiO_2	100
Titano-magnetite	Magnetite (Fe_3O_4) with variable TiO_2	Variable up to 25

[1]Lindgren, W., The Relation of Ore Deposition to Physical Conditions, Econ. Geology, 1907, vol. II, p. 125.

[2]Emmons, W. H., A GeneticClassification of Minerals, Econ. Geology, 1908, Vol. III, p. 621 *et seq.*

[3]Compiled from Dana, E. S., A System of Mineralogy; Hintze, C., Handbuch der Mineralogie: and Bull. No. III-A, Va. Geol. S., pp. 10-11.

LIST OF TITANIUM MINERALS—CONTINUED

Mineral	Composition	Contains TiO_2 Per Cent
Titanates:		
Ilmenite	$FeTiO_3$	52.7
Pyrophanite	$MnTiO_3$	53.1
Geikielite	$MgTiO_3$	67.7
Perovskite	$CaTiO_3$	58.9
Pseudobrookite	$Fe_4(TiO_4)_3$	42.9
Arizonite	$Fe_2O_3.3TiO_2$ or $Fe_2Ti_3O_9$	58.8
Knopite	$RO.TiO_2$. Closely related to perovskite but contains cerium	54.1–58.7
Iserite	$FeTi_2O_5$	69.5
Titano-silicates:		
Titanite	$CaTiSiO_5$	40.8
Schorlomite	$3CaO.(Fe, Ti)_2O_3.3(Si, Ti)O_2$	12.5–22.1
Keilhauite	$15CaTiSiO_5.(Al, Fe, Y)_2(Si, Ti)O_5$	26.7–36.6
Guarinite	$CaTiSiO_5$	40.8
Tscheffkinite	Related to keilhauite but uncertain	16.1–21.2
Astrophyllite	$(Na, K)_4(FeMn)_4Ti(SiO_4)_4$	7.1–13.6
Aenigmatite	$2Na_2O.9FeO.AlFeO_3.12(Si, Ti)O_2$	5.6
Cossyrite	Similar to aenigmatite	Undetermined
Yttrotitanite	See keilhauite	See keilhauite
Lamprophyllite	Related to astrophyllite	Undetermined
Neptunite	$R_2RTiSi_4O_{12}$	18.1
Johnstrupite	A complex silicate of the cerium metals, Ca and Na chiefly with Ti and F	7.6
Mosandrite	Very near Johnstrupite	5.3– 9.9
Rinkite	Near Johnstrupite and mosandrite	13.4
Ivaarite	Similar to schorlomite	18.98
Carlosite	Same as neptunite	18.1
Benitoite	$BaTiSi_3O_9$	19.3
Lorenzenite	$Na_2(TiO_2)Si_2O_7$	35.2
Yttrocrasite	A hydrous titanate of the yttrium earths and thorium	49.7
Delorenzite	$2FeO.UO_2.2Y_2O_3.24TiO_2(?)$	68.9
Davidite	TiO_2 with Fe, U, V, Cr, and rare earths	50.0+
Narsarsukite	Acid titano-silicate of ferric iron and sodium	14.0
Niobates and Tantalates:		
Pyrochlore	$RNb_2O_6.R(Ti, Th)O_3.NaF$	5.4–13.6
Aeschynite	$R_2Nb_4O_{13}R_2(Ti, Th)_5O_{18}$	21.2
Polymignite	$R(Nb, Ta O_3)_3.5R(Ti, Zr) O_3)_3$	18.9
Euxenite	$R(NbO_3)_3.R_2(TiO_3)_3.\frac{3}{2}H_2O$	20.0–23.5
Polycrase	$R(NbO_3)_3.2R_2(TiO_3)_3.3H_2O$	25.2–29.3
Blomstrandite	A niobate, tantalate, and titinate of uranium	10.7
Dysanalyte	$6RTiO_3.RNb_2O_6$	40.6–59.3
Strüverite	$FeO(Ta, Cb)_2O_5.6TiO_2(?)$	44.0
Epistolite	$Nb_2O_5.SiO_2.TiO_2.Na_2O.H_2O(?)$	7.2
Blomstrandine-Priorite	Niobates and titanates of Y, Er, Ce, and U	21.9–32.9
Marignacite	Same as pyrochlore	2.9
Ilmenorutile	$FeO.Nb_2O_5.5TiO_2$	53.0–73.8
Silicates:		
Amphibole	$CaR_3(SiO_3)_4$. Variable amounts of TiO_2	As much as 8.5
Pyroxene	$CaR(SiO_3)_2$. Variable amounts of TiO_2	As much as 4.6
Biotite	$(H, K)_2(Mg, Fe)_4(Al, Fe)_2(SiO_4)_4$. Variable amounts of TiO_2	Variable up to 4.7
Lepidomelane	Iron mica, with variable amounts of TiO_2	Variable up to 4.7
Rosenbuschite	$6CaSiO_3.2Na_2ZrO_2F_2.(TiSiO_3.TiO_3)$	6.9– 7.6
Titanolivine	Olivine$(Mg, Fe)_2SiO_4$ with variable TiO_2	3.5– 6.1

LIST OF TITANIUM MINERALS—CONTINUED

Mineral	Composition	Contains TiO_2 Per Cent
Silicates—*Con.*:		
Andradite	$Ca_3Fe_2(SiO_4)_3$; also $Ca_3Fe_2((Si, Ti)O_4)_3$ with variable TiO_2	Variable up to 10.8
Leucosphenite	$Na, Ba(TiO_2)(Si_2O_5)_3$	13.2
Rhönite	$(Ca, Na_2, K_2)_3Mg_4Fe_2Fe_2Al_4(Si, Ti)_6O_{30}$	9.5
Miscellaneous:		
Hydrotitanite	Altered form of dysanalyte	82.8
Warwickite	Perhaps $6MgO.FeO.2TiO_2.3B_2O_3$	23.5
Zirkelite	$(Ca, Fe)O.2(Zr, Ti, Th)O_2$	14.95
Derbylite	$6FeO.5TiO_2.Sb_2O_5$	34.6
Lewisite	$5CaO.2TiO_2.3Sb_2O_5$	11.7
Mauzeliite	$4(Ca, Pb)O.TiO_2.2Sb_2O_5$	7.9
Hainite	Composition doubtful, probably allied to mosandrite	Undetermined
Senaite	$(Fe. Pb)O.2(Ti, Mn)O_2$. Uncertain	57.2

North Carolina Localities

Ilmenite (Menaccanite). Some of the magnetic iron ores of North Carolina are titaniferous magnetites, while others are composed largely of ilmenite. These ores are described in considerable detail in Bulletin 1 of the Survey publications and, therefore, only a very brief notice will be given here of their occurrence. Such ores are found in Ashe, Caldwell, Iredell, Macon, Madison, Mitchell and Surry counties.

It has also been found in crystals and cleavable masses in many of the pegmatites of western North Carolina.

Rutile. This mineral has been found in many localities throughout North Carolina and, in one instance, gives promise of occurring in commercial quantity. This locality is in Clay County, near Elf postoffice on the Samuel Hogsed farm, where large, rough, almost black crystals of rutile are found quite abundantly in the soil. These rutile crystals vary in size from three-eighths inch to an inch or more in diameter. Thus far the original source of this rutile has not been determined.

It has also been found in well developed crystals up to three-eighths inch in diameter near Bryson City, Swain County; at the head of Cane Creek, Mitchell County; at the Ray mine, Yancey County; in beautiful crystals at Crowder and Chubb mountains, Gaston County; in large crystals at Hildebrand's, Burke County; in large crystals at E. Balch's, H. Balch's, Huffman's and D. Lutz's, in Catawba County[1]; as small and large, brilliant, well developed crystals associated with hiddenite near Hiddenite, Alexander County; and in small crystals associated with corundum at the Cullasaja mine, Macon County, the Hogback mine in Jackson County, and near Bakersville, Mitchell County.[1]

[1]F. A. Genth, Bull 74, U. S. Geol. Survey, p. 36, 1891.

In the form of acicular crystals, rutile has been found in Alexander County,[1] on John Lackey's farm near Liberty Church, at Wilson's, near Poplar Springs, at White Plains, Crouch's and at Milholland Mill. There has been found in Alexander County some of the most beautiful rutile crystals ever found anywhere. They have been found as much as three inches long and one-half inch in diameter, of a beautiful red color. Some of them are often geniculated. Some very good gems have been cut from this rutile that compare very favorably with the black diamond from Brazil. Associated with the ruby corundum of Caler Fork of Cowee Creek, Macon County, rutile has been found in small grains and crystals.

Other localities where acicular crystals of rutile have been found are: in crystals up to one inch long near Beattie Ford, Mecklenburg County; in long crystals in quartz near Buckham Falls, Chatham County; on Mrs. Daniel's farm near Mount Pisgah, on Mrs. Jordan's farm near Kings Mill, at Alex. Lackley's, Misses Bennett's, Thomas Adams' and Mrs. Smith's farms in Iredell County; at Dietz's, Van Horn's and Hildebrand's in Burke County. Associated with and penetrating quartz (amethyst) forming in many instances beautiful specimens of rutilated quartz (Venus hair stone). It has been found in brownish amethyst at the head of Honey Creek, Wilkes County; in amethyst at Huffman's and D. Lutz's in Catawba County; and near Concord, Cabarrus County; in the northwest corner of Lincoln County.[2]

In the gold and monazite placer deposits of Burke, McDowell, Rutherford, Polk, Macon, Alexander and Cleveland counties small grains and crystals of rutile have been found more or less abundantly. It has also been found in beautiful crystals in white radiated pyrophyllite in John Sykes' land at Rock Springs postoffice, near Efland, Orange County.

Anatase.[3] In the gold sands of Burke County, anatase has been found in small brilliant tatular crystals; also in quartz from Alexander, McDowell, and Rutherford counties. Crystals of unusual size were found at the Brindletown gold mine, Burke County.

Brookite.[3] This mineral has been found in the gold sands of Rutherford, McDowell and Burke counties. It occurs in small rhombic crystals varying in color from dull yellow to brown.

Titanite (sphene). This mineral has been found at several localities throughout western North Carolina. F. A. Genth[3] has observed it at Morganton Springs, Burke County, in minute brown crystals; in hornblende slate and in granite at White Mills, Gaston County; at Rogers' ore bank, near Danbury, Stokes County; on Hurricane Mountain, Yan-

[1]F. A. Genth, Bull. 74, U. S. Geol. Survey, p. 36, 1891.
[2]Ibid., p. 37.
[3]Ibid., p. 60.

cey County; in mica schist associated with oligoclase near Statesville, Iredell County.

Small titanite crystals of a brownish-red color have been found at the Hasket lime quarry in Cullowhee Gap, Macon County. Small crystals have also been found near Paint Gap, Madison County, in a granitic rock.

At the Jones zircon mine, near Tuxedo (Zirconia), Henderson County, good unaltered crystals of titanite have been found. Some larger crystals have been found which are nearly to entirely altered to a mineral called *xanthitane*. Some of these altered products contain a nucleus of unaltered titanite.

Zirconium

Zirconium has been experimented with in the manufacture of incandescent lamps and some have been manufactured and tested; but, up to the present time, they have not become a commercial success. The zirconium filament is supposed to give a very slightly greater efficiency than the tungsten but its profitable life is very much less.[1]

The tungsten-zirconium alloy filament is described under Tungsten. The source of zirconium is the mineral zircon.

Osmium

Another filament lamp that was devised by Auer Von Welsbach is the osmium lamp. While some of these lamps were manufactured, they never became of commercial importance, principally because of the scarcity of osmium and the high cost of the material with which the filament has to be made. Von Welsbach has estimated that there are only a few hundred pounds of osmium available in the periphery of our globe.[2]

Molybdenum

Considerable experimental work has been done in an attempt to use metallic molybdenum as a filament for incandescent electric lights. Thus far no commercial lamps have been produced, due, probably, to the low melting point of molybdenum. The pure metal can be drawn into wire and a very small amount of molybdenum wire is used in the manufacture of tungsten incandescent lamps as a support for the tungsten filaments.

Molybdenum is ordinarily obtained as a bluish black powder, but it can be converted into the bright metal by use of the thermite process or in the electric furnace. This metal may be drawn into a wire which is tougher and stands much rougher treatment than tungsten wire.[3]

The principal use of molybdenum is in the manufacture of certain chemical reagents, especially ammonium molybdate, which is used in the

[1]Engineer (Cleveland, N. Y.), Dec., 1906, p. 569; and U. S. Geol. Survey, Min. Res., 1906, p. 523.
[2]Chas. Baskerville, Jour. Ind. and Eng. Chem., Vol. VI, p. 182, 1914.
[3]U. S. Geol. Survey, Min. Res., 1908, p. 747, 1911, p. 955, 1912, p. 969.

determination of phosphoric acid. It is also used in the preparation of "blue carmine" for the coloring of porcelain. Another more recent use is in the manufacture of the alloy, ferro-molybdenum, which is used in the preparation of a special steel. It is often supposed that molybdenum is used at times in place of tungsten in the manufacture of hard steels, but each have certain valuable properties that they give to steel, which the steel manufacturers are rapidly beginning to appreciate. It is not, then, unreasonable to expect that there will be an increased demand for this metal and a wider market, which will warrant persistent prospecting for the mineral carrying it.

The metal molybdenum was discovered in 1778. When obtained in the metallic state it is in the form of a gray powder having a specific gravity of 8.6. It scarcely aggregates, even under the influence of a most powerful heat. It is not acted upon by the air at the ordinary temperature.

In testing for molybdenum, consideration must be made as to whether it occurs as a sulphide or in an oxidized condition. A good test[1] for the sulphide of molybdenum is to heat a fragment of the mineral on the flat surface of a piece of charcoal for a considerable time in the oxidizing flame, there being deposited at a short distance from the assay a coating of molybdic oxide, MoO_3. This is pale yellow when hot and almost white when cold. This oxide is volatile in the oxidizing flame, but if touched for an instant with a moderately hot reducing flame it assumes a beautiful ultramarine-blue color. Nearer the assay the charcoal is covered with a thin tarnished copper-colored coating of MoO_2, which is best seen when cold and by reflected light.

When the molybdenum occurs in the oxidized state, it is tested for by treating a very small amount of the powdered molybdate with a scrap of paper about as large as the head of a pin in a test tube with about five drops of concentrated sulphuric acid and an equal amount of water and heating until copious white fumes arise. Then on cooling, the liquid will assume a magnificent deep blue color which has resulted from the reduction brought about by the organic matter of the paper. If heated, the blue color will disappear, but will appear again upon cooling.

Occurrences and Localities

The sources of supply of molybdenum are the two minerals molybdenite, the molybdenum sulphide (MoS_2), and wulfenite, the lead molybdate ($PbMoO_4$). The former mineral usually occurs in foliated masses or in scales with a perfect basal cleavage and metallic lustre. It is very soft, being only 1 to 1.5 in hardness, and is readily scratched with the

[1]Penfield's Determinative Mineralogy, 1898, p. 95.

finger nail. It is of a pure lead-gray color and is often mistaken for graphite, which it sometimes very closely resembles, but can be distinguished by its color, which is of a very bluish gray; by its streak on paper, which is gray to bluish gray, while graphite is black; and by its behavior before the blowpipe, molybdenite giving off sulphur dioxide, which can be readily detected by its odor, while there is no change when the graphite is heated. It crystallizes in the hexagonal system; but well-developed crystals are rare, as they are usually rough and striated.

Wulfenite occurs commonly in square tabular, tetragonal crystals that are sometimes very thin, also granularly massive. It has a resinous to adamantine lustre and ordinarily an orange-yellow to bright red color. It is usually found in veins carrying other lead minerals.

The trioxide, MoO_3, the mineral molybdite has been found sparingly in tufts or radiations of rhombic crystals of a straw yellow color, and usually associated with molybdenite. Molybdenite generally occurs embedded in or disseminated through crystalline rocks, principally in granite, gneiss, syenite and granular limestone and it has been found sparingly in these rocks at many localities, there being but few localities where it has thus far been found in commercial quantity.

In the United States molybdenite has been found in quantity in the vicinity of Crown Point, Chelan County, Washington; at the Castleman mine, Whatcom County, Washington; at Cooper, Washington County, Maine; near East Los Vegas, San Miguel County, New Mexico; in the Santa Rita Mountain District, Pima County, Arizona; at the Leslie mine, Shoshone County, Idaho; near Portage, Atkin County, Minnesota; and in Beaverhead County, Montana, about thirty miles northeast of Dillon. It has also been found in some quantity two miles east of Ophir, Montana.

Wulfenite has been found in quantity in several localities in Pinal County, Arizona, and has been mined at the Mammoth mine in the southeastern portion of Pinal County, on the Rio San Pedro River, and at the Troy mine in the eastern part of the county.

NORTH CAROLINA LOCALITIES.

Molybdenite. This mineral has been found sparingly at several localities in Piedmont and western North Carolina, but thus far there has been no deposit discovered that gives any indication of containing the mineral in commercial quantity. It has been found in fine scales at several of the gold and copper mines of the State; at the Pioneer Mills mine, Cabarrus County; at the Peach Bottom copper mine, Alleghany County; at the Hasket lime quarry, Cullowhee Gap, Macon County; on

Tremont Mountain, Macon County; and at the Ray mica mine, Yancey County.

Molybdite.[1] At the Pioneer Mills mine of Cabarrus County, molybdite has been found as a yellow earthy powder coating molybdenite.

Uranium

Among the other metals that have been experimented with for use in metallic filaments in incandescent lamps is the vanadium group. Both vanadium and uranium have been tested but were soon proved to be of no commercial value for this purpose, due principally to their low melting point.

The reduction of the uranium compounds as they occur in nature, so as to obtain this metal in a chemically pure condition, is attended with considerable difficulty. For this reason, chemical compounds and alloys of uranium are produced to a much greater extent than the metal. Uranium was first recognized as an element in 1782 by the chemist Klaproth, and was named after the planet Uranus. It is a steel-gray nonmagnetic metal which is softer than steel, being readily scratched by a file.

Besides the experimental work with uranium for use in lighting apparatus, it has also been tried as a steel hardening metal, but thus far no decisive commercial results have been obtained. Other uses of uranium compounds are in the manufacture of porcelain and glass. The two oxides U_2O_5 andU_3O_8 are greatly prized for producing a pure black glaze on porcelain. For the decoration of glass and chinaware, a hydrated sodium uranate, known as uranium yellow, and a hydrated ammonium uranate are used, which give permanent colors. These two compounds are also used in the manufacture of a uranium glass, which possesses the property of absorbing certain chemical active light rays, and has a green-yellow fluorescence and is sometimes employed for ornaments. Certain uranium salts are used to a considerable extent in photography.

All of the uranium minerals have become of special interest on account of the uranium being the source of radium. In an article on the origin of radium[2] Mr. B. B. Boltwood, of New Haven, Conn., has given data which seem to show that uranium is the source of radium and also that there is a constant proportionality between the uranium and the radium in the various minerals containing these elements. A long series of minerals have been analyzed by Mr. Boltwood for their uranium and radium contents. It is interesting to note that the uraninite from the Flat Rock mine, North Carolina, showed the highest radio-activity of any of the minerals examined. In the following table are given the

[1] F. A. Genth, Bull. 74, U. S. Geol. Survey, 1891, p. 40.
[2] Philos. Mag., April, 1905, p. 599.

mineral substances tested, their locality, their uranium content, and the activity of the emanation contained in one gram of the mineral:

LIST OF URANIUM MINERALS EXAMINED FOR RADIOACTIVITY

Substance	Locality	Per Cent of Uranium	Activity of Emanation
Uraninite	North Carolina	74.65	150.7
do	Colorado	69.61	147.1
Gummite	North Carolina	65.38	126.7
Uraninite	Joachimsthal	61.74	131.8
Uranophane	North Carolina	51.68	108.0
Uraninite	Saxony	50.64	112.5
Uranophane	North Carolina	49.84	88.8
Thorogummite	do	33.17	61.1
Carnotite	Colorado	22.61	41.6
Uranothorite	Norway	11.38	24.9
Samarskite	North Carolina	10.44	23.2
Orangite	Norway	10.34	22.84
Euxenite	do	8.71	19.8
Thorite	do	7.54	15.6
Fergusonite	do	5.57	11.95
Æschynite	do	4.52	9.98
Xenotime	do	.70	1.14
Monazite	North Carolina	.43	.88
do	Norway	.41	.84
do	Brazil	.31	.76
do	Connecticut	.30	.63
Allanite	North Carolina	.007	.014

Occurrence

There are many minerals containing uranium that are known at the present time, but they are for the most part found sparingly and some of them are only known from one locality. The only ones that have been found in sufficient quantity to become a source of uranium are uraninite, gummite (an alteration product of uraninite), and carnotite.

Uraninite, or as it is more commonly known pitchblende, is a uranate of uranyl and lead with usually thorium (or zirconium) and sometimes with the metals of the lanthanum and yttrium groups. Certain varieties contain nitrogen, and several of the newly discovered and rare elements, as helium, radium, and polonium. This mineral is usually massive and botryoidal, with a conchoidal to uneven fracture, and is brittle. Crystals are rare, the octahedron being the common form. It has a hardness of 5.5 and a specific gravity of 9 to 9.7. In appearance it is often pitch-like, having a submetallic to greasy and dull lustre, and a grayish, greenish-black to velvet-black color.

Uraninite, which is the name given to the crystallized variety, occurs as a constituent in many pegmatitic dikes and coarse granites, and is the variety that generally carries the rare earths and nitrogen. The

massive variety, pitchblende, usually contains none or but a very small amount of the rare earths and nitrogen, and is more commonly found as an associate in metalliferous veins, with the sulphides of silver, lead, copper, nickel, iron, and zinc.

Uraninite suffers alteration quite readily going over into the hydrated mineral, gummite, which looks like gum, and whose exact composition is not known. Crystals of gummite are observed only as pseudomorphs after uraninite; and it is more often in rounded or flattened pieces, with a greasy lustre and a reddish yellow to orange, hyacinth-red or reddish brown, color, the brighter colors being the more prominent. It is only 2.5 to 3 in hardness and has a specific gravity of 3.9 to 4.2. As would be naturally expected, gummite is to be found at nearly all the uraninite localities, masses of this mineral often being observed with nuclei of uraninite in the center. It has not been found as a distinct mineral. A further alteration of the uraninite, through gummite, is to the mineral uranophane or uranotil, which is found in masses of a fine fibrous structure, with a vitreous lustre and a honey-yellow, lemon, or straw-yellow color. It is a hydrous silicate of calcium and uranium and besides being found as an alteration product, it also occurs as a distinct mineral. It is not uncommon to find the uranophane surrounding a mass of gummite, in the center of which is a nucleus of uraninite.

At present the principal occurrences of uraninite are at the Wood, Black Hawk and Kirk mines, near Central City, Gilpin County, Colorado. It is also found in Colorado in the La Sal Mountains, at the head of Paradox Valley, in Montrose County, and at Cat Gulch, near Turret, Shasta County, and on Dolores River at the mouth of Disappointment Creek, 80 miles west of Dolores, Montezuma County. In South Dakota, at the Ross-Hannibal mine, in the Ruby Basin of the Black Hills, uraninite has been found, but not in sufficient quantity to mine. In many of the pegmatitic dikes and metalliferous veins of Montana, California, and New Mexico (in the President mine, near Elizabethtown, Colfax County) uranium minerals have been sparingly observed.

In the eastern part of the United States uraninite occurs in many of the pegmatitic dikes. At many of the feldspar quarries in Connecticut it has been sparingly found, as at a quarry near Middletown; at Hale's quarry in South Glastonbury; at Branchville, where it often occurs in small octahedral crystals embedded in albite. Uraninite has been observed at Marietta, South Carolina, and at the famous gadolinite locality in Llano County, Texas.

Another uranium mineral that is worthy of note in connection with the above is autunite, sometimes called uranite, a hydrous calcium

uranium phosphate, $CaO.2UO_3.P_2O_5.8H_2O$, which is practically always found with uraninite and other uranium minerals. It occurs in small scales or foliated aggregates with micaceous structure on the feldspar and mica, or with galena, sphalerite, argentite, chalcopyrite, and the minerals associated with the uraninite in the dike or vein. It has a pearly and adamantine lustre and a lemon to sulphur-yellow color, and is one of the indications of the presence of other uranium minerals. It is sometimes called uranium mica, as is also the mineral tobernite. (See below.)

The other uranium mineral that has become of economic importance is carnotite,[1] which has been recently discovered in Montrose County, Colorado. It occurs as a yellow to reddish-yellow crystalline powder or in loosely cohering masses that are easily separated by the fingers and leave traces on whatever touches them. When tested, the mineral was found to contain not only uranium, but also a considerable percentage of the valuable metal vanadium. Analysis shows it to be composed mainly of a hydrous vanadate of uranium and potassium. The purer varieties contain about 52 per cent of uranic oxide (UO_3), about 18 per cent of vanadium pentoxide $(V_2O_5)_3$, about 5.5 per cent of potash (K_2O), and only about 5 per cent of silica (SiO_2).

Other Minerals Containing Uranium

In the following list the name and composition of the minerals containing uranium in sufficient amount to classify them as uranium minerals are given:

Uranothallite, a hydrous calcium uranium carbonate, $2CaCO_3U(CO_3)_2.10H_2O$ occurs very sparingly as an incrustation of a siskin-green color on uraninite.

Liebigite, a hydrous calcium uranium carbonate, formula perhaps $CaCO_3(UO_2)CO_3.20H_2O$, occurs rarely as an apple-green crystalline incrustation on uraninite.

Voglite, a hydrous carbonate of uranium, calcium, and copper, of an emerald-green to grass-green color, is sparingly found in aggregates of crystalline scales implanted on uraninite.

Schröckinergite and randite are two uranium calcium carbonates of uncertain composition.

Some of the varieties of thorite contain a considerable quantity of uranium as uranothorite, which carries over 9 per cent of uranium oxide, U_2O_3, and is found in the Champlain iron district, New York, but whose exact locality is unknown.

[1]Mining and Scientific Press, August 25, 1900.

A number of the niobium and tantalum minerals contain from 2 to 15 per cent uranium oxide. They are, in the order of their percentage of uranium: Blomstrandite, hatchettolite, samarskite, polycrase, euxenite, fergusonite, ythotantalite, annerödite, and hielmite.

Uranosphærite, a hydrous bismuth uranate, $(BiO)_2.U_2O_7.3H_2O$, occurs sparingly in half-globular aggregated concentric forms of an orange-yellow color.

Torbernite, a hydrous phosphate of uranium and copper, $CU(UO_2)_2 P_2O_8$ plus $8H_2O$, occurs in foliated micaceous aggregates of an emerald to grass-green color, closely resembling autunite.

Zeunerite is a hydrous copper uranium phosphate, $Cu(UO_2)\ As_2O_8$ plus $8H_2O$, similar in appearance to torbernite.

Uranospinite is a hydrous calcium uranium arsenate, probably $Ca(UO_2)_2\ As_2O_8$ plus $8H_2O$, and similar to autunite, but rare.

Uranocircite is a hydrous barium uranium phosphate, $Ba(UO_2)_2P_2O_8$ plus $8H_2O$, similar to autunite, but very rare.

Phosphuranylite, a hydrous uranium phosphate, $(UO_2)_3P_2O_8$ plus $6H_2O$, sometimes carrying lead, is found sparingly as a deep lemon-yellow incrustation on quartz and feldspar at some of the uraninite localities in North Carolina.

Trögerite, a hydrous uranium arsenate, $(UO_2)_3As_2O_8$ plus $12H_2O$, in thin lemon-yellow crystals, has been found very sparingly at the Bald Mountain mining district, Black Hills, South Dakota.

Fritzcheite, a mineral resembling autunite, but of a reddish color, which is attributed to manganese, is of doubtful composition, but shows reactions for uranium, vanadium, manganese, phosphorus, and water.

Walpurgite, a basic arsenate of bismuth and uranium, $Bi_{10}(UO_2)_3(OH)_{24}(AsO_4)_4$, is very rare.

Johannite is a hydrous sulphate of uranium and copper, of a beautiful emerald-green color.

Uranopilite, a hydrous calcium uranium sulphate, perhaps $CaU_8S_2O_{31}..25H_2O$, has been found as a velvety incrustation of a yellow color on uraninite.

Uraconite or uranocher is an amorphous earthy mineral of a fine lemon-yellow color, whose composition is principally a hydrous uranium sulphate.

Medjidite, uranochalcite, zippeite and voglianite are uranium sulphates of uncertain composition, containing from 36 to 79 per cent of uranium oxides.

Vanadium

Since the discovery of this metal in the early part of the nineteenth century, by Del Rio, and its rediscovery and investigation by the Swedish chemist Sefstroem in 1830, it has been shown to be quite widely distributed in nature, but for the most part in very small quantities. The metal is obtained with difficulty in the form of a brilliant metallic powder of a silver-white color.

It is, however, the compounds of vanadium that are employed in the arts; and, as our knowledge of these increases, and more is known of the valuable properties which they possess, there is a growing demand for them. Its main use, in the form of vanadic acid (V_2O_5), is as a mordant in dyeing (aniline black). Other vanadium compounds are used to a limited extent in the coloring of glass. As a steel hardening metal, vanadium is beginning to be used in some quantity in the manufacture of a vanadium steel which goes largely into the manufacture of of springs and gears for automobiles.

Occurrence

Formerly the supply of vanadium came from France, where it is obtained from certain slags at Creusot. With the discovery, however, of the mineral carnotite and the pure vanadate mentioned above, a new source of supply has been opened.

The metal is widely distributed, having been found in certain clays, iron ores (especially magnetite), coals, and in trap and basaltic rocks, besides the numerous vanadium minerals. It is, however, usually in but minute quantities, although some magnetites have been found that contained sufficient vanadium to make them profitable working.

Another source of vanadium, and one that has attracted and is still attracting the interest of manufacturers and chemists, is its existence in the ash of certain coals. It was first discovered in a lignite coal found at San Rafael, in the province of Mendoza, Argentine Republic, by Dr. Juan J. J. Kyle.[1] In testing the coal as to its value as a combustible, Dr. Kyle found that it left but a small amount of ash, which was of greenish color. On analyzing the ash, it was found to contain vanadium, and in some quantity. From the results of the analyses, it shows that one ton of the coal will produce over 14 pounds of pure ash containing 4½ pounds of the vanadic acid (V_2O_5), of which 3½ pounds may be extracted by simple treatment of the ash with an alkaline liquor, while the remainder can be extracted by a more elaborate chemical process. In Cordoba and San Louis, neighboring provinces of Mendoza,

[1]Buenos Ayres Standard, Jan. 30, 1894, and U. S. Consular Reports, 1894.

the vanadium minerals, vanadite, descloisite, and psittacinite, have been found at a number of localities.

Vanadium has also been found in an anthracite coal mined near Yauli, in Peru. With this discovery, the probability of finding vanadium in coals in other parts of the world is increased, and it may be that a careful examination of the coals from the United States, especially of the western states, will show the presence of the metal.[1]

In analyzing the peats of eastern North Carolina, Dr. Charles Baskerville[2] found minute quantities of vanadium to be present in some of them, up to 0.003 per cent of P_2O_5.

In a recent investigation by Dr. W. F. Hillebrand,[3] on the distribution of vanadium, he shows that in the more basic igneous and metamorphic rocks there occurs up to 0.08 per cent or more of V_2O_3, but that it is apparently absent in the highly siliceous rocks. The source of the vanadium in the rocks appears to be the heavy ferricaluminous silicates, biotites, amphiboles, pyroxenes. Sometimes the vanadium occurs in considerable amount in these minerals, when they are given distinctive names, as roscoelite,[4] the vanadium mica, and lavrovite,[5] a variety of the pyroxene diopside.

Besides the two minerals referred to under "Uranium" as containing an available source of vanadium, there are a number of other minerals that also carry this, but they have not been found as yet in sufficient quantity to be a source of vanadium.[6]

VANADIUM MINERALS

The principal vanadium minerals are given below:

Vanadinite is a mineral usually occurring in hexagonal prisms which generally have smooth faces, but are apt to be cavernous, and are brittle, breaking with an uneven fracture. Its hardness is 2.75 to 3, and its specific gravity 6.6 to 7.2. The color of vanadinite varies from ruby-red, reddish-brown, light brownish-yellow to straw-yellow, and it has a resinous lustre. It is a lead vanadate, whose formula is $(PbCl)Pb_4(PO_4)_3$, and is commonly found associated with other lead minerals, especially in the western states, where it has been found in some quantity in the silver-mining regions of Arizona and New Mexico, in red and orange crystals; in the former State, at the Vulture and Phoenix mines, in Maricopa County; the Mammoth Gold mine, near Oracle, Pinal County, and in Yuma County. In New Mexico it has been found at

[1]Eng. and Min. Journal, Aug. 15, 1894; Jan 26, 1896; Feb. 24, 1900.
[2]Jour. Am. Chem. Soc., Vol XXI, 1899, p. 707.
[3]Bull. U. S. Geol. Survey, No. 167, 1900, p. 49.
[4]Analyses, Hillebrand. Bull. U. S. Geol. Survey, No. 167, 1900, p. 70.
[5]Dana Mineralogy, 1892, p. 356 and Kk. Min. Russl., Vol. VI, p. 206.
[6]Mining Reporter, July 6, 1899, p. 16.

Lake Valley, Sierra County; at the Mimbres mines, near Georgetown, Grant County, and at Los Cerillos. It has also been found in the Leadville district of Colorado. At Zimapan, in Mexico, vanadinite has been found in some quantity in yellowish, reddish-brown to red crystals, and it was from this locality that this mineral was first discovered.

Endlichlite is a variety of vanadinite that contains a considerable percentage of arsenic in a ratio that is nearly P:As=1:1.

Descloizite has been found in small crystals, and also massive, with fibrous structure and mammillary surface of a cherry red and brownish-red to light or dark brown color and greasy lustre. In hardness this mineral is 3.5, and has a specific gravity of 5.9 to 6.2. Chemically it is a hydrous lead-zinc vanadate, having the formula $(PbZn)_3V_2O_8(PbZn)(OH)_2$. This is usually the composition of the crystallized varieties. Another variety, containing copper (as high as 11 per cent), occurs in crusts and reniform masses. It is found in some abundance at Lake Valley, Sierra County, and near Georgetown, Grant County, in New Mexico; near Tombstone, Cochise County, in Yavapai County, and at the Mammoth Gold Mine, near Oracle, Pinal County, in Arizona.

Eusynchite, brackebuschite, and aræoxene are minerals similar and the first perhaps identical with descloizite.

Pucherite is a bismuth vanadate of a reddish brown color, usually occurring in small tabular crystals.

Psittacinite is a vanadate of lead and copper, which has been found in thin coatings of a siskin to olive-green color in the Silver Star district of Montana.

Mottramite is a vanadium mineral found in some considerable quantity at Alderly Edge and Mottram St. Andrews, in Cheshire, England, and may be identical with psittacinite.

There are a number of vanadium minerals of uncertain composition that are probably vanadates. These are chileite, a vanadate of lead and copper; vanadiolite, a dark emerald-green calcium vanadate containing silica; wicklowite, a doubtful lead vanadate.

Volborthite is a hydrous vanadate of copper, barium, and calcium, of an olive-green color occurring in small six-sided tables.

Roscoelite is a vanadium mica that has been observed in minute scales of a clove-brown to greenish brown color at the gold mine at Granite Creek, near Coloma, Eldorado County, California. In the Magnolia district, Colorado, earthy incrustations of this mineral have been found on calaverite.

Ardennite is a vanadio-silicate of aluminum and manganese, also containing arsenic, which is found rarely in small prismatic crystals of a yellow to yellowish-brown color, having a hardness of 6 to 7.

In the pyroxene group of minerals, a variety of diopside called lavrovite is colored green by vanadium.

Dechenite and calciovolborthite are two vanadates that have been found very sparingly, the former being a lead and the latter a hydrous copper-calcium vanadate.

Tests for Uranium and Vanadium

The following tests can be used to advantage in detecting uranium and vanadium in minerals:

Uranium.[1] Make a small salt of phosphorus (hydrogen sodium ammonium phosphate, $HNaNH_4PO_4.4H_2O$) bead on platinum wire. To this add a little of the powdered mineral to be tested. The oxide of uranium is soluble, and before the blowpipe in the oxidizing flame it converts the colorless bead to a clear yellow, which becomes yellowish-green on cooling, while after heating in the reducing flame the bead assumes a fine green color. When there are other elements in the mineral that will impart color to the bead and for the detection of small quantities of uranium, it is best to proceed as follows: Dissolve the mineral in hydrochloric acid (after fusion with sodium carbonate, if necessary), nearly neutralize the excess of acid with ammonia, add solid ammonium carbonate, shake vigorously, and allow the liquid to stand a few minutes. The uranium is at first precipitated, but is soluble in excess of ammonium carbonate, and by filtering may be separated from a great many elements which are precipitated by that reagent. Sometimes there is difficulty in obtaining a clear filtrate, and, if so, a few drops of ammonium sulphide may be added with the ammonium carbonate. Boil the filtrate containing uranium to expel carbon dioxide, add ammonia in excess, collect the precipitate containing uranium on a filter and test it with a salt of phosphorus bead, as described above.

Vanadium.[2] Test with a salt of phosphorus bead, as described under "Uranium." The color of the bead in the oxidizing flame is yellow to deep amber, fading slightly on cooling, while in the reducing flame it is an indistinct dirty green, which changes to a fine green on cooling.

If there is but a small amount of vanadium in the mineral or there are other oxides that will impart color to the bead, the powdered mineral should be fused with about four parts of sodium carbonate and two of potassium nitrate in a platinum or porcelain spoon. After cooling,

[1] Penfield's Determinative Mineralogy, 1898, p. 129.
[2] Op. cit., p. 130.

the fusion should be digested with warm water, in order to dissolve out the soluble alkali vanadate. Filter, acidify the filtrate with a slight excess of acetic acid, and add a little lead acetate, which will precipitate a pale-yellow lead vanadate. (Lead chromate, which would be precipitated in the same process, is much yellower.) The precipitate, after being collected on a filter paper, can be tested with the phosphorus bead.

NORTH CAROLINA LOCALITIES

At many of the mica mines in western North Carolina, uranium minerals have been sparingly found, as the Flat Rock mine near Spruce Pine, Mitchell County. Uraninite has been found in masses as large as three pounds. These masses, however, were largely altered to gummite and uranotil. This mine has produced the larger amount of uranium minerals produced in North Carolina. At the Deake mine, also near Spruce Pine, there is a similar occurrence of uraninite and gummite. At the Thompson mine, just beyond the Deake, a mass of uraninite and gummite was found that weighed two pounds. The uranophane has been observed at many more of the mica mines in this vicinity, and other parts of Mitchell, Avery and Yancey counties. Uranium minerals have also been found sparingly at the Wiseman mine, Mitchell County, and the Ray mine, Yancey County. No vanadium minerals have thus far been found in North Carolina.

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